ECONOMIC BOTANY

DEVOTED TO APPLIED BOTANY AND PLANT UTILIZATION

Publication of
THE SOCIETY FOR ECONOMIC BOTANY

On The Formation of the Society for Economic Botany

The Use of Cytoplasmic Male-sterility in Hybrid Seed Production
DONALD N. DUVICK

The Utilization of Mustards
J. G. VAUGHAN AND J. S. HEMINGWAY

Agriculture and Economic Development in India
P. MAHESHWARI AND S. L. TANDON

Recent Highlights in the Chemurgy of Xerophytic Plants
ROBERT R. CRUSE

Cassava Leaf Protein
DAVID J. ROGERS

Book Reviews

Abstract Bibliography of Fruit Breeding and Genetics to 1955
Nomenclature of Plants
Algae: The Grasses of Many Waters
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ON THE FORMATION OF THE SOCIETY FOR ECONOMIC BOTANY 165

THE USE OF CYTOPLASMIC MALE-STERILITY IN HYBRID SEED PRODUCTION
Donald N. Duvick 167

THE UTILIZATION OF MUSTARDS
J. G. Vaughan and J. S. Hemingway 196

AGRICULTURE AND ECONOMIC DEVELOPMENT IN INDIA
P. Maheshwari and S. L. Tandon 205

RECENT HIGHLIGHTS IN THE CHEMURGY OF XEROPHYTIC PLANTS
Robert R. Cruse 243

CASSAVA LEAF PROTEIN
David J. Rogers 261

Book Reviews

ABSTRACT BIBLIOGRAPHY OF FRUIT BREEDING AND GENETICS TO 1955. — 204

NOMENCLATURE OF PLANTS — 204

ALGAE: THE GRASSES OF MANY WATERS — 264

EDIBLE WILD PLANTS OF EASTERN NORTH AMERICA — 265

On the formation of
THE SOCIETY FOR ECONOMIC BOTANY

The following is a report from an Interim Committee on the formation of a Society for Economic Botany. The committee was appointed at an informal conference on Economic Botany held at The New York Botanical Garden August 12-13, 1958. (See "Report on Economic Botany Conference" Econ. Bot. 12 (4): 405-420. 1958).

"In September, 1958, a questionnaire was widely distributed to survey interest in the founding of a society for economic botany. More than three-fourths of those who returned questionnaires indicated they would join such a society. A large majority favored the name THE SOCIETY FOR ECONOMIC BOTANY. Reaction to possible affiliation of the society with other societies was mixed, but a majority indicated that the society should remain independent until the membership decided otherwise.

"With this very encouraging reflection of interest, the Committee then asked three outstanding men to serve as an Advisory Council to the Committee. Constitution and By-Laws for the proposed society were drafted by the Interim Committee and reviewed and approved by the Advisory Council. The Constitution and By-Laws provided a framework within which we could ask a slate of *pro-tem* officers and councilmen to serve until a regular meeting of the members of an established society can be held.

"The New York Botanical Garden has offered their journal ECONOMIC BOTANY for adoption as the official organ of the Society, under terms very favorable to the Society. The *pro-tem* Council, under authority vested in it by the Constitution, effected an Agreement with The New York Botanical Garden whereby ECONOMIC BOTANY, beginning with Volume 13, 1959, becomes the official organ of the Society. Under the terms of the agreement, members of the Society will receive ECONOMIC BOTANY at an annual rate of $6.00 *which is included in the dues.* Nonmembers may subscribe to the journal but at the rate of $8.00 per volume.

"Because of the name, THE SOCIETY FOR ECONOMIC BOTANY, people in disciplines other than botany may have the impression that this is a society composed only of botanists. Article II *(Definition and Objective)* of the Constitution should remove any such impression:

"The field of economic botany is defined, for the purpose of this Society, as all activities which pertain to the past, present, and future uses of plants by man. It is recognized that this broad definition includes all or parts of many established disciplines such as: agronomy, anthropology, archaeology, chemistry, chemurgy, economics, ethnology, forestry, geography, geology, horticulture, medicine, microbiology, pharmacognosy, pharmacology, in addition to the established botanical disciplines. THE SOCIETY FOR ECONOMIC BOTANY endeavors to bridge the gaps between such recognized fields of science by promoting interdisciplinary channels of communication.

"The composition of the pro-tem Council, the governing body of the Society, also reflects the interdisciplinary nature of our Society:

"*Chairman:* C. O. Erlanson, Chief, New Crops Research Branch, U.S.D.A., Beltsville, Maryland

Wheeler McMillen, Chairman of the Board, The Chemurgic Council, New York

L. G. Nickell, Head, Phytochemistry Laboratory, Chas. Pfizer & Co., Inc., Brooklyn, New York

W. C. Steere, Director, The New York Botanical Garden, New York

I. A. Wolff, Chief, Industrial Crops Laboratory, U.S.D.A., Peoria, Illinois

H. W. Youngken, Jr., Dean, College of Pharmacy, University of Rhode Island, Kingston, R. I.

"The *pro-tem* officers of the Society are:

President: Ernest Guenther, Chemist and Vice President of Fritzsche Brothers, Inc., New York

Secretary: Quentin Jones, Botanist, U.S.D.A., Beltsville, Maryland

Treasurer: David J. Rogers, Curator of Economic Botany, The New York Botanical Garden, New York

"It is tentatively planned to have the first meeting of the Society in April, 1960. Place, dates, and program of the meeting will be announced sufficiently early to invite participation.

"Classes of membership have been designed to accommodate several categories of individual and institutional members. Article II of the By-Laws is here quoted:

"ARTICLE II. Classes of Members.

Section 1. Individual Members.

Subsection a. Annual Members. Persons who are interested in any aspect of economic botany and who shall pay annual dues of seven dollars and fifty cents ($7.50).

Subsection b. Life Members. Persons interested in the purposes of the Society, who shall pay one hundred dollars ($100.00).

Subsection c. Patrons. Persons interested in the aims and objectives of the Society who contribute two hundred dollars ($200.00) or more to its support.

Section 2. Institutional Members.

Subsection a. Affiliate Members. Institutions which support the Society by annual contributions of one hundred dollars ($100.00).

Subsection b. Sustaining Members. Institutions which support the Society by annual contributions of two hundred and fifty dollars ($250.00) or more."

Anyone who wishes to make application for membership in the Society should write to

Dr. David J. Rogers
New York Botanical Garden
Bronx Park
New York 58, New York

Interim Committee on Organization
QUENTIN JONES
L. G. NICKELL
DAVID J. ROGERS

The Use of Cytoplasmic Male-sterility in Hybrid Seed Production

The practical utilization of heterosis in crop plants has been greatly facilitated during the past 15 years by the use of cytoplasmic male-sterility for low-cost, large-scale emasculation of the seed parents of hybrids. The method is now being used in commercial production of hybrid onions, sugar beets, field corn, grain sorghum, and petunias. Its use is contemplated for hybrid sweet corn, pop corn, red table beets, fodder beets, fodder sorghum, pearl millet, carrots, and garden peppers.

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Introduction

When the practical importance of heterosis was demonstrated by the development and use of hybrid corn *(Zea mays* L.), plant breeders naturally considered hopefully the possibilities for utilization of hybrid vigor in other crops. With few exceptions, however, it was apparent immediately that corn's special kind of monoecism made it unique among cultivated crops. Corn could be emasculated cheaply on a large scale simply by pulling out the immature tassels. Most other crop plants bear anthers and stigmas in the same flower, or at least in closely associated flowers, so that emasculation is tedious and requires a relatively high degree of technical training and ability. The possibilities, therefore, for economically successful large-scale production of hybrid seed of crops other than corn were considered to be limited.

History of Studies

Genetic Male-sterility. It was known, of course, that many plant species, including most crop plants, contained genes for male-sterility. These genes usually were inherited as simple Mendelian recessives. Such genetically male-sterile plants were thus "self-emasculated" and could easily be crossed to pollen-fertile plants with no further preparation. The male-sterile genotypes, however, obviously could be propagated only in heterozygous condition since a male-sterile plant could not be selfed or intercrossed with other male-sterile plants. Thus, for purposes of hybridization, the line to be used as a pollen-sterile female would at best be segregating about one-half fertiles. These would have to be rogued out at considerable expense and often could not be detected before they had shed some of their contaminating pollen. Only in certain crops could one economically use this relatively expensive method for mass hybridization.

Early Evidences of Cytoplasmic Male-sterility. As early as 1904 Correns (16) had found that in the common summer savory *(Satureja hortensis* L.) all the progeny of a hybrid between a strain which produced only female flowers and a gynomonoecious strain were female (i.e. male-sterile) like the mother. This later was explained by von Wettstein (120) as due to the effect of the mother's cytoplasm, although East (27) also proposed a purely genetic scheme, involving gamete selection, which fit the data.

Bateson and Gairdner (6) in 1921 described a type of male-sterility in the fiber and oil-seed flax (*Linum usitatissimum* L.) which was inherited only through the female although its expression was controlled by genes which could be contributed by either parent. In this case also, crosses could be made which gave all male-sterile progeny. Chittenden and Pellew in 1927 (13) stated that this sterility was due to an interaction between cytoplasm and genotype, saying that sterility-inducing cytoplasm plus a homozygous recessive gene caused pollen sterility. The gene was without effect in "normal" cytoplasm, the cytoplasm commonly carried in normal pollen-fertile flax varieties.

Rhoades in 1931 and 1933 (94, 95) described a type of pollen sterility in corn (*Zea mays*), which was inherited only through the female. Here too, all progeny were male-sterile, or nearly male-sterile. The male-sterility was attributed by Rhoades to the mother's cytoplasm. He apparently concluded (see 95, p. 75, 77, 84) that genotype had no demonstrable effect on the sterility induced by the particular type of cytoplasm he studied. In actuality, his data do indicate that there was an effect of genotype on expression of the cytoplasmically-induced male-sterility.[1] For example, a chi-square test shows that in five out of 17 tests shown in table XIV of the 1933 paper the constitution of the pollen parents significantly affected the percentage of male-sterile plants in their progeny. The total chi-square for all 17 tests shows a highly significant effect of pollen parent on percentage of male-sterile plants, with cytoplasm held constant. In table XV of the same reference, the segregations of fertiles to steriles for 38 selfed "normal-appearing" plants are recorded. The ratio of the pooled data for these 38 progenies comes remarkably close to that expected for a 9:7 segregation ($P = 0.7$) and an interaction chi-square indicates no significant difference among progenies. These data would be in agreement with the hypothesis that two dominant genes were required to overcome the sterility induced by the cytoplasm. It is of course true that further breeding tests would be required to substantiate such a hypothesis. Now, Rhoades did state that "most, if not all, of the normal-appearing plants are actually male-sterile individuals which for some reason are phenotypically normal" (95, p. 77). It seems reasonable to conclude that the reason could be a genetic control of the cytoplasmically-induced sterility.

First Attempts to Utilize Cytoplasmic Male-sterility. At least two corn breeders, D. F. Richey and H. A. Wallace, recognized that the Rhoades sterile perhaps might be used to eliminate the detasseling step in production of hybrid seed corn (97). They, and breeders associated with them, immediately set about back-crossing the Rhoades sterile (as female) to several commercially usable inbred lines of corn (2, 97, 110). Although their two breeding programs were entirely separate, both had the same planned sequence of events. The first step was to make an inbred in which all plants would be pollen-sterile (a cytoplasmically pollen-sterile line). This line would be maintained by perpetual backcrossing to its normal-cytoplasm, pollen-fertile counterpart. The male-sterile inbred would be crossed to a second normal-cytoplasm, pollen-fertile inbred to give a cytoplasmically pollen-sterile single cross. All plants of the single cross would be pollen sterile. This sterile single cross then could be used as the seed parent for production, without detasseling, of double-cross hybrid seed. The double-cross hybrid, a cross of two single crosses, is the usual type of commercial corn hybrid.

[1] A similar conclusion with regard to Rhoades' data has been reached by W. H. Gabelman in his Ph.D. dissertation entitled "Cytogenic studies of cytoplasmic inheritance of male sterility in *Zea mays*", on file at Yale University.

It was expected that the double cross also would be cytoplasmically pollen sterile; so the breeders assumed that part of the double-cross seed planted by the farmer would have to be of a normal-cytoplasm, pollen-fertile type, produced in the usual hand-detasseled fashion. Thus, two kinds of each double-cross hybrid would be produced and mixed before planting (97, 110). The plants in the farmer's field would be pollinated by those plants with normal cytoplasm and would set normal quantities of seed.

Unfortunately for the hopes of the corn breeders, several of the supposedly male-sterile strains sometimes shed some pollen (2, 97, 110). Apparently the cytoplasmic sterile was not reliably sterile. For this reason the initial enthusiasm for utilization of cytoplasmic pollen sterility dimmed rapidly (2, 97, 110). Breeding of male-steriles was discontinued and within a few years (by about 1936) all seed of the Rhoades cytoplasmic male-sterile had disappeared. No account of the breeding schemes for utilization of cytoplasmic male-sterility nor of the results of their breeding experiments was published by the early workers. Knowledge of the idea and of the results was limited, therefore, to a relatively small group.

Would the use of the cytoplasmic sterility factor in hybridizing have come considerably earlier had those corn breeders who worked on the problem in the 1930's realized that the expression of sterility was influenced by the genotype? We can never know now whether the Rhoades' cytoplasm was one for which reliably sterilizable genotypes could have been found or developed. Furthermore, it must be remembered that in the '30's labor was plentiful and detasseling corn had not yet come to be regarded as a severe problem. Without the example of successful use of cytoplasmic sterility in hybridizing other crops, it is possible that in the '30's the long program possibly necessary to find or develop suitable sterilizable genotypes might not have seemed as desirable as spending the time on other more immediately beneficial research.

First Successful Use of Cytoplasmic Male-sterility for Hybridization——the Onion. In 1924 a downy mildew-resistant onion plant (*Allium Cepa* L.) was isolated by H. A. Jones (58, 59) in the variety Italian Red and was designated Italian Red 13-53. Subsequent plantings and examinations revealed that this plant could not make self-pollinated seed due to male-sterility, but luckily it produced bulbils, and therefore it was propagated by means of them. Interest in use of the male-sterility of the 13-53 clone for making commercial hybrid onions later developed (59), and for this reason the inheritance of its sterility was investigated by Jones and Clarke, who published the results of their investigations in 1943 (57). They showed that the sterility of the 13-53 clone was due to an interaction of cytoplasm and genes, much like that described for flax by Chittendon. The combination of 13-53 cytoplasm (designated "S" cytoplasm) and a homozygous recessive gene *(ms ms)* produced pollen sterility. The *ms ms* genotype was without apparent effect in normal (N) cytoplasm, the cytoplasm usually found in normal pollen-fertile onions.

Fig. 1. Male-sterile (l.) and normal fertile (r.) onion flowers at time of blooming. The male-sterile flower is slightly older than the normal flower. Note difference in size of anthers between the two flowers. (Photograph courtesy A. E. Kehr, U.S.D.A. Hort. Crops Res., Beltsville, Md.)

Jones and Clarke recognized that they now had the potential means for large scale hybridization of almost any two lines of onions. They were no longer limited to using only 13-53 as a female parent. It was required merely that one find a normal (N) cytoplasm, pollen-fertile line of the genotype *ms ms*. This then could be made pollen sterile by repeated backcrossing to 13-53 (S cytoplasm) using the normal cytoplasm (N *ms ms*) line always as pollinator. The new male-sterile line (now designated S *ms ms*) then could be crossed on a field scale with any other pollen-fertile line, provided flowering dates coincided. Onion pollen is carried from plant to plant by various insect species. Jones and Clarke realized that this method of selection, backcrossing, and large-scale hybridization could be applied to other crops as well, saying "The type of breeding program just outlined should be applicable to any crop plant in which male sterility is inherited in this way, provided that the plant, like the onion, is naturally cross-pollinated and displays hybrid vigor in the F_1" (57, p. 193). Their paper appears to have been the first published account of a scheme to utilize cytoplasmic male-sterility to emasculate hermaphrodite plants for the purpose of large-scale hybridization.

Whether or not the hybrid onion was pollen-fertile was of course of no importance to the breeders if the hybrid was destined to be grown for market, since only the hybrid plant and not its

Fig. 2. Making crosses between individual onion plants. Flies are being introduced into the small cages to do the pollinating (Photograph and legend after Jones, H. A. and J. P. Sleesman, in Ohio Farm and Home Research **41**: 60-62. 1956.)

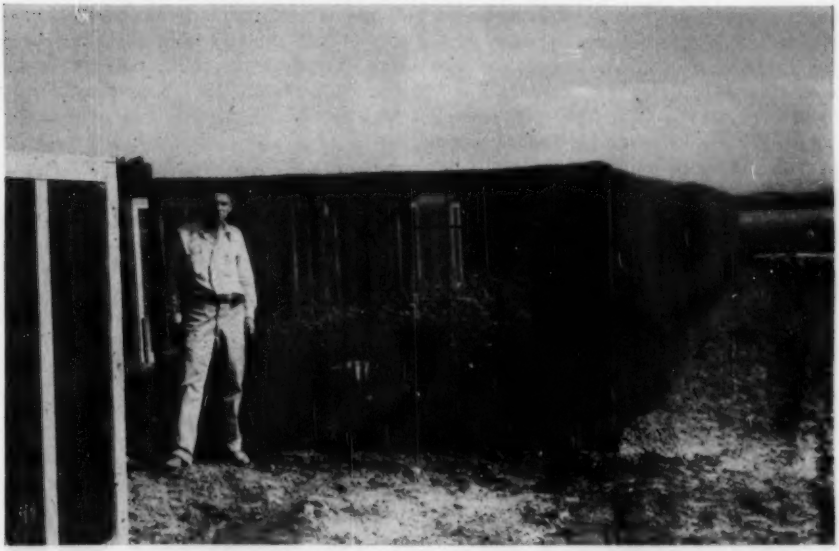

Fig. 3. Large screen cages used for the increase of seed of female onion lines, Parma, Idaho. Note hive of bees inside the cage. (Photograph and legend after Jones and Sleesman).

seed was desired. It may be important to note, however, that although the onion breeders were not usually concerned with fertility of the final commercial hybrids, they did utilize the effect of the *Ms* gene in S cytoplasm in their breeding programs. Hybrids of constitution S *Ms ms* (pollen fertile) were selfed and interpollinated in order to begin development of a new pollen-fertile variety (59). The release of "Calred" onion in March, 1947, at the University of California, resulted from such a program.

Commercial Application of the Method. Ten years passed after the publication of the Jones and Clarke paper before substantial numbers of proven hybrid onions were ready for the American market; but by 1953 hybrids began to be sold widely, and since then they have rapidly increased in numbers and acreage. Estimates of the actual percentage of total onion acreage now planted to hybrids vary from 7½% to 40%, but breeders and seedsmen alike agree that eventually virtually all onion seed planted will be hybrid (20, 56, 61, 118). To date the supply of hybrid seed never has been sufficient to meet the demand for it (61). Reasons for this demand are obvious; in the first place, yields of released hybrids usually are much greater than those of the varieties they have replaced. In Texas, as an outstanding example, hybrid Granex has shown a 94% increase in yield over the standard variety Texas Early Grano (1). Uniformity of the crop is important to onion growers, and the vigorous F_1 hybrids are superior to the heterogeneous varieties in uniformity of size, shape, and maturity. Disease resistance also can be more conveniently incorporated into hybrids.

Field hybridization of onions is effected by planting alternating blocks of male-sterile (female) and male-fertile (male) rows. Usually a ratio of one male row

to four female rows is used. Most of the pollination is accomplished by bees especially placed in the crossing fields, four or five hives to the acre (1). Only F_1 hybrids are grown for the commercial onion trade. Due to the need for a uniform product the heterogeneity shown by most double-cross hybrids would exceed the standards of acceptable uniformity.

Stability of Onion Cytoplasmic Male-sterility. After fifteen years of extensive experience with cytoplasmically pollen-sterile onions, American breeders say that the 13-53 cytoplasm remains apparently completely stable in performance (61). The simple genetic story still remains true, on the whole, although a few lines have been found which do not seem to fit the single gene, all or none hypothesis, at least under some environmental conditions (20). Barham and Munger (5) have found that moderately high temperatures would allow microspores in sterile plants to develop more than usual although they rarely or never developed into functional pollen even under such conditions. No changes other than that of pollen fertility have ever been noted as being caused by S cytoplasm. Although new sources of S cytoplasm have been discovered in American (88) and Turkish (19) as well as in Dutch, English, and German varieties, none of them seems to be different from the 13-53 source; and it therefore has been, with few exceptions, the only source utilized for making hybrids in this country.

Hybrid Onions in Europe. Hybrid onions made by means of cytoplasmic pollen sterility also are being developed in Europe. In the Netherlands, Germany, and England, breeding at first began with the 13-53 source, but in each country breeders soon isolated cytoplasmic male-sterile individuals in local adapted varieites and have used those as foundation

Fig. 4. Producing hybrid onion seed in southwest Idaho. The two center rows are pollen parent; on each side are rows of female plants. (Photograph and legend after Jones and Sleesman).

for their present breeding program (3, 4, 43, 65). The new sterile cytoplasms found in Germany and the Netherlands seem to be the same as the 13-53 type. Breeders report that, to date, no hybrids are on the market in any of these countries.

The *ms* gene seems to be widely distributed among onion varieties from many sections of the world (18, 67), so there should be little trouble in finding suitable sterilizable genotypes in any country.

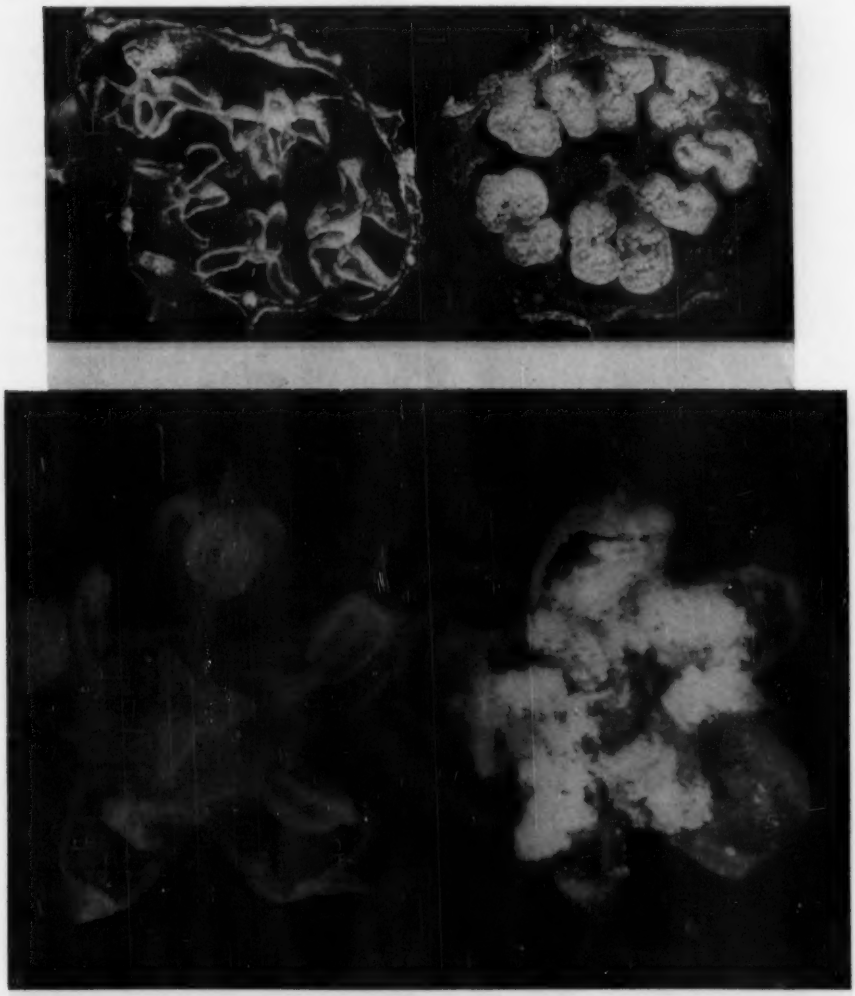

Fig. 5. (above) Male-sterile (l.) and normal (r.) sugar beet flowers, in cross-section in bud stage. After Owen, F. V. (79). (below) Male-sterile (l.) and normal (r.) sugar beet flowers, immediately after dehiscing. After Owen, F. V. (79).

Application to Other Crops

Shallot

The closest relative of the onion, sometimes even placed in the same species, is the shallot (*Allium ascalonicum* L.). It is easily hybridized with *A. cepa*. Little *et al.* (67) have found that the shallot contains both *Ms* and *ms* genes, as shown when it is crossed to the cytoplasmic male-sterile 13-53.

Sugar Beet Hybrids

Origin and Genetics. Jones and Clarke, in their paper describing cytoplasmic sterility in onions, cited an abstract by Owen (78) in which he gave a preliminary report of a similar phenomenon in sugar beets (*Beta vulgaris* L.). In 1945 Owen published in detail the record of his investigation of cytoplasmic sterility in sugar beets (79). In general, the genetic story was the same as that for onions, in that the beets carried genes which caused pollen sterility when in a particular cytoplasm. This cytoplasm had been found in several plants of the curly-top resistant variety U.S. 1 and in varieties derived from it. Owen found that the genetic situation was not as simple, however, as that for onions. There seemed to be at least two recessive genes, designated *x* and *z* by Owen, which controlled sterility in S (sterility-inducing) cytoplasm. If both genes were homozygous recessive, the sterility was complete. If only one of the two genes was homozygous recessive, the plants were incompletely sterile. If both genes were heterozygous, the plants usually shed some viable pollen and often were equal in pollen fertility to the normal cytoplasm beets. Owen noted, however, that in some instances the genetics of sterility was somewhat more complicated. Subsequent studies have borne this out (46, 76, 80, 81).

Method of Application. Owen noted in his 1945 paper that his discovery could be used to produce hybrid sugar beets on a field scale and showed a photograph of a crossing field in which hybrid seed was successfully produced. In 1948, after satisfying himself that male-sterile hybrid

Fig. 6. A sugar beet crossing field. Two center rows are pollinator parent. Male-sterile seed parent rows are on either side. For making seed of a preliminary hybrid which will be used in making the final hybrid in the next generation. (Photograph courtesy F. V. Owen, U.S.D.A. Sugar Crops Res., Salt Lake City, Utah).

beets were superior in yielding ability to open-pollinated varieties (80, 85), he published a scheme for producing cytoplasmic male-sterile lines by repeated backcrossing of selected *Nxxzz* lines into S cytoplasm, equivalent to that described for onions by Jones and Clarke. He then showed how such cytoplasmic male-sterile lines could be used to produce topcross, single-cross, three-way cross and also triploid hybrids.

In 1954 Owen also published a scheme for making double-cross sugar beets (83). The method used cytoplasmic sterility to produce the female single cross and a non-cytoplasmic type of genetic male-sterility (82) to produce the pollinator single cross. Use of genetic sterility to produce the male single cross necessitates roguing out the fertiles in the single-crossing field. Such an operation is laborious but would be required for only a relatively small acreage since the proportion of male single-cross seed needed to produce double-cross hybrids is quite small. It would seem at first thought that one might use cytoplasmic instead of genetic male-sterility to produce the pollinator single cross, by making the cross S*xxzz* x *NXXZZ* to produce a heterozygous, pollen-fertile F_1 which could be used as a pollinator. However, it seems that the genotype *NXXZZ* has not yet been identified with certainty (81, 84), and at any rate the S*XxZz* heterozygotes were not always completely normal in pollen production (79). The discovery by Hogaboam (46) of a dominant modifier (*Sh*) which enhances the pollen production of S*Xx* plants may make it possible to produce double-cross beets using cytoplasmic sterility to produce both the female and the pollinator single crosses. It may be worth noting that as with onions it is of little importance whether or not the final double-cross sugar beet hybrid produces pollen since growers are interested in the plant and not in its seed production.

Utilization of cytoplasmic pollen sterility for producing hybrid sugar beets has not been as easy as it was for onions for several reasons. In many cases the isolation of sterilizable genotypes has been difficult due either to their scarcity in the material being investigated or to the fact that the sometimes complex genetic situation makes it difficult to distinguish completely sterile plants from incompletely sterile plants. Further, the environment can affect at least some genotypes so that a genotype which is sterile in one environment may shed pollen in another. There also can be variations within a given plant so that the later flowers may be more fertile than the early ones (7, 46). This, of course, could be due to environmental change over time.

One of the greatest difficulties in producing hybrid sugar beets has had nothing to do directly with cytoplasmic sterility but rather has been one basic to any hybrid breeding program. Prior to discovery of cytoplasmic sterility there was no large-scale hybrid beet-breeding program. It takes time to produce usable inbreds and to find the best combinations of them. This is further complicated by the necessity to select at least two of the inbreds for their sterilizability and then to sterilize one of those two inbreds by backcrossing.

Nevertheless, the advantages of being able to combine increased yield with increased sucrose content, a combination very hard to breed into open-pollinated varieties, plus the ease of combining disease resistance factors from various sources, have outweighed the difficulties in the opinion of many breeders (21, 117), and work now has proceeded to the point where about one-fourth of the sugar beet production in the United States is hybrid, with the percentage rising each year (77, 117). Much of the present hybrid production is top cross or even variety cross, but the trend appears to be toward double-cross hybrids.

Monogerm Cytoplasmic Steriles. The conversion to production of hybrids

seems to have been speeded considerably in the last few years by the desire to utilize the recently discovered monogerm character for production of sugar beet seed. The monogerm character is determined by a single recessive gene *(m)* which causes the seed ball to contain only one viable seed instead of several (106). This means that planting rates can be controlled mechanically to a greater degree than ever before and that much of the expensive hand thinning can be eliminated. A quick and easy way to utilize the monogerm character for commercial production of monogerm seed is to put it into a cytoplasmic sterile line and then to use this monogerm male-sterile line, or a single cross between it and another sterilizable monogerm line, as seed parent for crossing with a satisfactory open-pollinated variety (86). A large percentage of the production of hybrid sugar beet seed in 1958 was of this type (77).

Hybrid Sugar Beets in Europe. The hybrid method for production of sugar beet seed also has been applied in Europe recently and several breeders are starting cytoplasmic sterile projects (7, 43, 45, 65). To date, however, very little hybrid seed has been sold although at least one company, in the Netherlands, does have a cytoplasmic male-sterile hybrid in large-scale production (45). The Dutch company, incidentally, utilizes not only cytoplasmic sterility but also takes advantage of the vigor of polyploidy by using a tetraploid pollinator on a diploid female so that the hybrid is a triploid. Triploid cytoplasmic steriles also are being produced commercially in England.

New Sterile Cytoplasms. Since Owen's initial isolation of S cytoplasm from U.S. 1 other breeders have discovered additional sterile cytoplasms in other beet varieties and also in a related species, *Beta macrocarpa* Guss. Savitsky (107) states that new sources which he has isolated (all from *B. vulgaris*) vary quantitatively in their effects on sterility, compared to each other and also to the original U.S. 1 sterile cytoplasm. Oldemeyer (76), however, states that preliminary investigation shows that two types he has discovered seem to be identical with the U.S. 1 sterile cytoplasm.

Fodder Beets

Fodder beets (*Beta vulgaris* L.) are an important crop in much of northern Europe. These now are being crossed to sugar beet sources of cytoplasmic sterility, and breeding work is under way to develop hybrid fodder beets in most northern European countries. At least one breeder plans to use cytoplasmic sterility for making a 100% triploid fodder beet (7).

Table Beets

Gabelman (40) recently introduced the S cytoplasm from U.S. 1 into red table beets (*Beta vulgaris* L.) and is proceeding to develop hybrid table beets. Work along this same line has been started in England also (43). The genetics of cytoplasmic sterility in table beets seems to be about the same as in sugar beets.

Corn: Second Trial of Cytoplasmic Male-sterility

It was mentioned above that the Rhoades cytoplasmic sterile for corn was tried and then discarded in the mid-1930's because it appeared to be too unstable with respect to pollen production. The idea and the hope were not given up altogether, however. Beginning in 1948 a series of papers which were published or presented to corn-breeding groups made it clear that work with the cytoplasmic male-sterile factor in corn had made possible the production of hybrid corn without detasseling. Work with a new and more reliably sterile type of cytoplasm was described by D. F. Jones and Everett (52). Jones and Mangels-

Fig. 7. Sterile (l.), partially fertile (c.) and fertile (r.) anthers of corn. Pollen has been shed from the last two types of anthers.

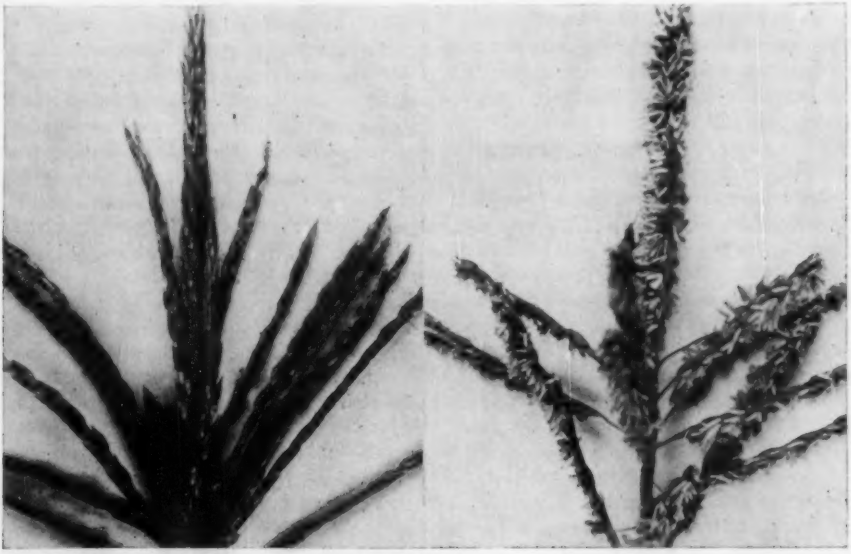

Fig. 8. Male-sterile (l.) and fertile (r.) corn tassels, shortly after normal time of flowering. Note that the sterile tassel has no exserted anthers. Cytoplasmic male-sterile corn ("Texas" type) differs from most other cytoplasmic male-sterile crops in that in corn those florets which contain only sterile anthers usually do not open at any time.

dorf (53), Rogers (100, 101), and Rogers and Edwardson (102). The source actually used in all cases had been isolated by Rogers in 1944 (102) at the Texas Agricultural Experiment Station as an individual plant in the open-pollinated variety, Golden June. Although the two above citations in which Jones was senior author attributed this source to Mangelsdorf, it was later stated by Jones *et al.* (54) that this cytoplasmic source, now known as the Texas or "T", had been received from Rogers. Proofs of interaction between genotype and cytoplasm of corn with respect to pollen sterility were presented in 1947 and 1948 by Josephson and Jenkins (60) and in 1949 by Jones and Everett (52) and by Rogers (100). This second information, which now placed corn cytoplasmic sterility on the same plane of understanding as that for onions and sugar beets, led the corn breeders (a) to the realization that they now could select reliably sterilizable genotypes and (b) to the belief that they could eliminate entirely the process of blending normal with cytoplasmic seed in the double cross planted by the farmer. They instead could use in the pollinator single cross one or two inbreds whose genes would restore pollen fertility to the cytoplasmic "sterile" double cross (52, 100). The final double cross then would shed enough pollen to produce seed for the farmer. Fortunately, "fertility restoration", as it came to be known, is dominant in corn. Proof of the practical workability of these two hypotheses was soon given when Rogers presented data (100, 101) showing that seed parent single crosses had been fully sterilized and that double crosses made from them had up to 40% fertile plants if one male inbred was a restorer and all fertile plants if both male inbreds were fertility restorers.

Both Jones and Rogers found in preliminary experiments that sterile cytoplasm seemed to introduce no deleterious agronomic effects; i.e., sterile hybrids performed about the same as normals (48, 53, 101, 102). Preliminary evidence obtained by Jones (48, 49) also indicated that the genetics of fertility restoration in Texas cytoplasm was simple, due probably to a single dominant gene, although limited data presented by Rogers (101) and Rogers and Edwardson (102) indicated that the genetics might be more complicated.

Sterility Adopted. With these assurances, therefore, the corn breeding fraternity soon moved strongly into production of "sterile" hybrids. In 1958 it was probable that over 50% of all hybrids sold were made at least in part by means of the cytoplasmic sterile method.

As is often the case, the change to cytoplasmic steriles was not as simple as had at first seemed possible. The genetics of fertility restoration turned out to be more complicated than it had appeared at first. The stability of pollen sterility of some of the cytoplasmic steriles in Texas cytoplasm was less than satisfactory. Isogenic hybrids compared in normal and in sterile cytoplasm sometimes turned out to be quite different in performance. And finally, the use of fertility restoration to eliminate blending was slower in arriving than had seemed probable at first. None of these difficulties was insurmountable, however; they slowed but did not stop the spread of the use of cytoplasmic male-sterility.

Restoration Genetics. Fertility restoration in Texas cytoplasm was found to require at least two dominant, independent genes, although most sterilizable inbreds lack only one of the two dominants (22, 54). In some environments (hot and dry during flowering) these genes were without full effect unless boosted by at least two dominant modifier genes (22, 25). Not all sterilizable inbreds were recessive for the same genes, so that a restorer line which had sufficient dominants for one inbred might be unsatisfactory for another.

Partial Restorers. Widespread testing of Corn Belt inbreds has indicated that about 60-75% of them are quite sterile when in Texas cytoplasm. About 5-10% of them are fully fertile in Texas cytoplasm, and the remainder are "partially fertile" (25, 29). This last class is a troublesome one; for the "partial restorers", as they are known, usually cannot be used to make a sterile single cross because partial fertility is dominant, more or less. On the other hand, they cannot be depended on for use as fertility restorers either because their pollen fertility fluctuates widely, depending on the environment at time of flowering. A partial restorer can be nearly normal in pollen production in one location, usually in cool, damp weather, and entirely sterile in another location or season, usually in hot, dry weather. Partial restorers, therefore, can be used only on the male side, and when in a fertility-restorer hybrid they further must be paired on the male side with a good fertility-restorer inbred. Some commercial hybrids have been found to have a partial restorer inbred in the female single cross, and these hybrids therefore cannot be produced as cytoplasmic steriles. It is possible, however, to re-breed some partial-restorer inbreds, substituting certain genes so that the inbred can be used to make sterile single crosses. Also, occasional inbreds prove to be heterogeneous with regard to partial restoration, and selection within the line can isolate sterilizable strains.

Yields of Steriles. Rather little information has been published on comparative yield tests of normal and sterile forms of hybrids. Since most "sterile" hybrids now are produced as blends of normal and sterile, it is important to know whether the sterile is equivalent in performance to the normal. Data published by Jones *et al.* (55) indicate that on the average there is little difference in yield between the normal and sterile forms of a hybrid and that if there is any consistent difference it is in favor of the sterile. Rogers and Edwardson (102) and Duvick (23) have published data indicating that the relative performance of a sterile hybrid compared to its normal counterpart may depend both upon the hybrid and upon the circumstances of the test. Duvick (23, 25) has concluded that, in general, it appears that when hybrids are under severe stress, such as drought, heat, and water shortage, at time of silking, the sterile hybrids will produce fewer barren plants and usually will out-yield their normal counterparts. Conversely, when growing conditions are at an optimum during this critical period, the final yield of the steriles tends to be slightly less than that of their normal counterparts. The amount of interaction with environment will vary with the individual hybrid. On the average, one can expect the differences to balance out so that yields of normals and steriles should be about the same in the long run. Stringfield (114) has published data indicating that restored hybrids in sterile cytoplasm may not yield the same as isogenic non-restored hybrids in sterile cytoplasm.

The reason for the slow progress in use of fertility restoration is more or less an accident of genotypes in Corn Belt inbreds. It has been relatively easy to produce "blend" hybrids, for as noted above most Corn Belt inbreds are sterile in Texas cytoplasm. They, therefore, can be sterilized by means of the quick and simple chromosome-replacement backcross method. This means that many of the currently used single-cross females can quickly be converted to a sterile form by backcrossing one of the two inbreds into sterile cytoplasm. Such sterile singles can then be used to make the sterile portion of a blend hybrid. Only a few Corn Belt inbreds have full restoration ability however, and these lines have only rarely occurred on the male side of the commercial double crosses which were made up before the restoration ability of the lines was known. Therefore, only a few Corn

Belt hybrids are "naturally restored." It is interesting to note, by way of contrast, that Edwardson found that 60% of Latin American varieties tested by him had fertility-restorer genes (29). Now it is true that non-restorer inbreds can be rebred into good restorer inbreds. Eckhardt (28) has described one of the best methods for doing this, a technique of backcrossing with selection for a fertility-restorer factor introduced by an initial out-cross. The method is more complicated than the simple chromosome-replacement backcross method used to sterilize a line, however, for one must transfer a piece of chromosme bearing a restorer gene from a restorer line into the corresponding chromosome of the non-restorer line which is to be converted. This means one must depend upon cross-overs and also must make careful selection in the backcross progenies. When it was discovered that for many inbred lines one had to transfer two, three, or more restorer genes (see above), the rebreeding program became much more complicated than had been anticipated. Further, when breeders attempted to speed up the program by growing winter generations in greenhouses or in Florida, it was found that selection for full restoration often was not fully effective in the winter generations, because modifier genes needed for full pollen fertility in the summertime often were not needed in the winter and therefore could not be identified in the wintertime. Apparently, cooler temperatures and-or higher humidity in Florida and in the greenhouse reduced the need for "booster" genes. Conversion of non-restorer lines into restorer lines has therefore taken more time and effort than was anticipated.

Without long delay, it is of course possible for breeders to make up new restorer-type hybrids which use the existing "natural" restorer inbreds. The total number of new hybrid combinations would be limited by this practice however, due to the scarcity of restorer inbreds for use on the male side. Chances for improvement, for selecting new hybrids superior to existing ones, would be greatly reduced.

It has been suggested that the use of cytoplasmic sterility in itself may have done a disservice to the hybrid corn industry, at least from the farmer's point of view, in that the seedsmen will be prevented from introducing new hybrids as fast as they might have done before the advent of cytoplasmic sterility (98). By the time four inbreds have been developed, tested, put together in the proper combination and then sterilized and converted into fertility restorers, many years have passed and one might be reluctant to go through this process again very soon. It has been pointed out, however (9), that seed corn selling is a competitive business in which the determining sales factor today is performance rather than price. Therefore, it is to be expected that cytoplasmic sterility will be looked upon as a useful production technique but not as an indispensable one. It will not be allowed to interfere with the main business of the corn breeder, which is the production of better hybrids.

New Sterile Cytoplasms. As with beets and onions, several additional sources of sterile cytoplasm have been discovered in corn. The actual count of known sterile cytoplasms of separate origin is not known at the moment, but it may well be near 100. Jones *et al.* list ten (54). J. L. Lonnquist has found five (68). The writer has 27 which differ in origin from those of Jones and of Lonnquist, although some of these are separate isolations out of one varietal source. Other breeders and geneticists from around the world have from time to time discovered instances of cytoplasmic sterility in corn now that their eyes have been sharpened to note and save such things. The most common source of new cytoplasmic steriles probably has been open-pollinated varieties of corn, but they also have

turned up in genetic tester stocks and even in inbred lines (8, 54, 60). Rhoades (96) has reported that the iojap gene *(ij)* can cause normal cytoplasm to change to a cytoplasmic male-sterile type, although his reported data do not exclude the possibility that his original iojap stock already contained sterile cytoplasm plus weak restorer genes. Sterile cytoplasms have been found in Russian, U. S. Corn Belt, Mexican, Turkish, Brazilian, and Peruvian varieties of corn (8, 25, 54), to name a few, so that there seems to be no monopoly on place of origin of cytoplasmic steriles.

Preliminary studies by Briggle (8) and by Duvick (24) have turned up the curious fact that nearly all sterile cytoplasms studied by them seemed to be identical either with the Texas type or the USDA type. The USDA type was discovered by M. T. Jenkins of the USDA and developed for commercial use by D. F. Jones (54). The USDA cytoplasm does not sterilize as many inbreds as does the Texas; and although it is used for some commercial production, it is not as generally useful. These two types can be distinguished by the fact that some lines will restore Texas but not USDA, while other lines will restore USDA but not Texas (8, 24, 50). Briggle compared five sterile cytoplasms to the Texas and the USDA types; Duvick compared ten different cytoplasms to the same two sterile cytoplasms. Three of the five cytoplasms studied by Briggle seemed to be about the same as USDA. The remaining two did not seem to resemble either Texas or USDA; but since they both were heterozygous, genetically, they could not easily be compared to the rest of the test. Seven of the ten studied by Duvick seemed to be the same as USDA, and the remaining three were like the Texas source.

The "Restorer Patent". The history of development and use of cytoplasmic male-sterility in corn is unique among those related in this article in that one of its processes, the use of fertility-restorer lines to produce a pollen-fertile "cytoplasmic sterile" hybrid corn, has been patented. The patent was issued in 1956 to D. F. Jones of the Connecticut Agricultural Experiment Station, who assigned it to the Research Corporation of New York, N. Y. (119). The patent does not cover the process of using cytoplasmic sterile females without fertility restoration, so that if one produced a hybrid by means of the blend method, producing part of the hybrid by detasselling and part with a cytoplasmic sterile female, the patent would not apply, providing the male single cross contained no restorer lines. However, if one uses on the male side of the hybrid "at least one inbred strain capable of restoring pollen fertility to cytoplasmic male-sterile corn" (119), he then may be subject to licensing requirements of the patent holders, if the patent is valid.

The patent is something entirely new in the field of plant (and animal) breeding, and its future progress will be watched with interest by plant and animal breeders alike. It is not a patent under the plant patent laws but is instead an extraordinary "method" patent under the ordinary patent laws.

Sweet Corn

The hybrid sweet corn (*Zea mays* L.) industry is not as advanced in use of cytoplasmic male-sterility as is the hybrid field corn industry. Although the genetics of cytoplasmic male-sterility is about the same in sweet corn as in field corn, sweet corn breeders and seedsmen have moved more slowly for two main reasons: they have been afraid blend hybrids would lack the desired uniformity; and the scarcity of fertility restoration in good sweet corn inbreds has meant the breeders have had to wait until rebreeding projects were completed before they could produce restored cytoplasmic sterile hybrids (10, 42). Most sweet corn is sold as single-cross hybrids because the trade demands

an extremely uniform product. Good fertility-restorer inbreds are, if anything, less numerous in sweet corn than in field corn. Sweet corn breeders have been hesitant to use field corn fertility restorers as a source of restorer genes because they know from experience that field-corn germplasm often introduces deleterious quality characteristics into sweet corn. They therefore have first surveyed the sweet corn germplasm to locate good fertility-restorer genes and have, in general, then used these as a source of restoration for backcrossing programs.

At the present time very little seed of cytoplasmic male-sterile sweet corn hybrids has been produced, but breeding work is expanding rapidly, and it is presumed that eventually much of the sweet corn seed sold will have been made by means of the cytoplasmic male-sterile method, utilizing fertility restoration to provide pollen in the final hybrid (10, 42).

Pop Corn

Pop corn (*Zea mays* L.), like sweet corn, is grown on a much smaller scale than is field corn, and also like sweet corn the seed has a higher price per bushel, so that detasseling expenses are not as important a cost item as they are for field corn. Pop corn breeders have been working hard recently on the problem of transferring into various pop corn lines a series of genes which will serve to prevent contamination of the seed-production fields by field corn pollen. This breeding problem has taken precedence over that of utilization of cytoplasmic male-sterility to eliminate detasseling; and therefore breeding work with pop corn cytoplasmic sterility is not as advanced as is that for field corn, although it is well under way with good prospects for eventual widespread use (115).

The genetics of fertility restoration seem to be about the same in pop corn as in sweet and field corn. The percentage of good fertility-restorer inbreds is quite low, compared to field corn, but the sterilizable pop inbreds do seem to have on the whole a better supply of dominant modifiers of the major restorer genes than do field corn inbreds (115, 116).

Cytoplasmic Male-sterility in Sorghum

Breeders of grain sorghum (*Sorghum vulgare* Pers.) had known for years of the yield increases which hybrid sorghum could give, compared to the open-pollinated varieties. Like other breeders, they had tried various genetic male-steriles for production of hybrids, but they too eventually turned to cytoplasmic sterility recognizing that this technique should be the best solution to their problem (92). The search for a cytoplasmic sterile sorghum was intensified in 1946 (92, 112), inspired largely by the successes with onions and sugar beets. Sorghum, like most grasses, has perfect flowers. It is wind-pollinated but normally is highly self-fertilized. Artificial emasculation is difficult and slow.

Discovery of "Sterile" Sorghum Cytoplasm. The discovery of cytoplasmic male-sterility in sorghum was made in an interesting way, more or less by accident. It was an accident that could have happened, however, only to a trained geneticist who was, in a sense, looking for just such an occurrence. In 1950, while attempting to determine whether or not a cytoplasmic condition was responsible for the sterility of the "Day" male sterile (a type later shown to be non-cytoplasmic), J. C. Stephens noticed some partially male-sterile plants in some of the control populations which had been expected to be entirely male-fertile (92, 113). These were F_2 populations of Double Dwarf Yellow Sooner milo x Texas Blackhull kafir. He further noted that the F_2 populations of the reciprocal cross, made with the kafir as the female, contained only normal fertile plants. This differential performance of the reciprocal

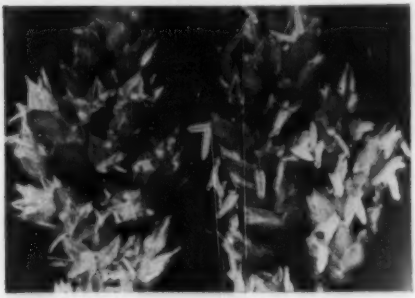

Fig. 9. Male-sterile (l.) and normal fertile (r.) Kafir sorghum, at time of blooming. Note the smaller anthers on the male-sterile sorghum. (Photograph courtesy J. C. Stephens, U.S.D.A. Cereal Crops Res., Chillicothe, Texas).

hybrids led Stephens to suspect a cytoplasmic effect on pollen fertility. The suspicion was intensified by the observation, made in the same year, that some progenies of the backcross, (Day male-sterile x kafir) x kafir, were almost entirely male-sterile instead of the expected 50% sterile. The Day variety originated from a milo variety and presumably has milo cytoplasm. Further experimentation by Stephens and Holland (113) showed that when kafir-type sorghum plants were backcrossed as male to hybrids which had been made with milo-type sorghum as the female, substantial numbers of male-sterile plants were obtained. In some BC^2 progenies more than 99% of the plants were male-sterile. When the male-sterile plants were crossed, as female, to milo plants, the progeny once again were pollen-fertile. It was concluded, on the basis of this evidence, that pollen sterility was caused by interaction between milo cytoplasm and kafir nuclear factors. (Sorghum varieties can be classified into several groups, based on morphological characters. Two of these groups are the kafir and the milo.)

Scheme for Practical Application. When the above data were published by Stephens and Holland in 1954, it was suggested by them that one probably could make cytoplasmic male-sterile kafir sorghum by backcrossing it into the cytoplasm of a milo sorghum. The male-sterile

Fig. 10. Sorghum crossing field. Twelve center rows are male-sterile seed parent. The darker colored blocks of four rows each on either side of the male-sterile block are the pollinator rows. (Photograph courtesy Lindsey Seed Co., Lubbock, Texas).

line then could be hybridized on a field scale with any milo type which was of fertility-restoring nature with respect to milo cytoplasm. This would give rise to a pollen-fertile F_1 hybrid suitable for use by the farmer. In sorghum, as in corn, the hybrid must shed pollen in order to make a crop of grain for the farmer. Stephens and Holland did not imply that all kafir-type sorghums necessarily would be sterilizable in milo cytoplasm, nor that all milo-type sorghums would have (a) the type of milo cytoplasm they had discovered nor (b) full fertility restorer powers. They stated that probably many strains of sorghum would prove to be intermediate in fertility restoration.

In 1956 about 24 million pounds of hybrid sorghum seed were produced in the United States; and in the following year about three million acres, probably about 15% of the total grain sorghum acreage, were planted to hybrid grain sorghum (92). This was only three years after publication of the Stephens and Holland paper. In 1958 it is estimated that at least 50% of the grain sorghum acreage in the United States was hybrid (2).

Problems of Sorghum Hybrids. Considering the speed with which breeders and seedsmen have moved into producing hybrid sorghum seed, remarkably few serious problems have turned up. Probably the most serious problem of the hybrids is one which is indirectly due to the fact that they are hybrids. When two normally strong-stalked sorghum varieties are hybridized, the increased yield of the hybrid often puts too much strain on the stalk (both mechanically and physiologically), and the hybrid tends to stalk-lodge badly. Standing ability always has been one of the greatest problems for sorghum breeders and the advent of hybrids has accentuated this problem.

Problems of out-crosses due to stray pollination have become greater, for there is more opportunity for out-pollination to occur in a crossing field, especially one in which the flowering dates of the two parents do not coincide very closely or in which the pollen parent proves to be a poor shedder. All grain sorghums in commercial use today are dwarf types, depending usually on three recessive genes for their shortness. The dwarfing is necessary for ease of combine harvesting. An outcross plant quite often might be heterozygous for one or more of the recessive dwarf genes and, thus, would make itself exceedingly visible and bothersome at harvest time.

As predicted by Stephens and Holland, many sorghum varieties are the troublesome intermediate fertility-restorer type. These resemble partial cytoplasmic steriles in other crops in that they react to environment in marked fashion so that one must test widely and carefully to be sure he has a true sterile or a true restorer line. In sorghum, pollen fertility of the cytoplasmic steriles generally increases as temperature increases and decreases as temperature decreases (62). This correlation is the opposite of that for corn but the same as reported for onions.

Restorer Genetics. Maunder and Pickett have presented data showing that male-sterility (in milo cytoplasm) is due to a single recessive gene (71). Observations by them and by other breeders have indicated that not only a dominant restorer gene but also several modifiers probably are needed for full expression of fertility restoration, at least in some locations (62, 70, 112). In some cases also, the percentage of complete steriles in segregating populations is less than expected on the basis of single gene segregation (112). In general the genetics of restoration, from the point of view of handling it on a practical basis, seems quite complicated.

Future Breeding Plans. Breeding work on hybrid sorghum has concentrated at first on testing all present varie-

ties (these normally are so highly inbred that they can be treated as inbred lines) for presence or absence of fertility-restorer genotype, then sterilizing all varieties that can be sterilized readily, and finally hybridizing such steriles with known fertility-restorer varieties. These single-cross hybrids are then tested and the agronomically acceptable ones retained. Several good hybrids have been produced in this way, but future breeding work will be concentrated on developing new inbreds meant only for hybridization.

Stephens and Holland mentioned the interesting possibility that some of the other taxonomically diverse sorghum groups such as durra, feterita, kaoliang, or shallu might carry cytoplasms which can sterilize genotypes not now sterilized in milo cytoplasm. Preliminary investigations of this important problem have recently been started by Ross (103), but further generations are needed before pertinent data will be available.

Forage Sorghums

Forage sorghums (usually used for ensilage or dry fodder) are closely related to grain sorghums, and it has been found that many of them can be sterilized in milo cytoplasm. The possibility of making hybrid forage sorghums is especially inviting to seed producers because, by a judicious selection of parents, the seedsman can harvest his seed from a dwarf, easily combined female; and yet the farmer can grow a hybrid which is of the tall type preferred for high yields of forage (91). To do this it is necessary only to use as male a tall type having in dominant form the genes which as recessives cause the dwarfing in the female seed parent. The heterozygous hybrid then will also be tall. Hybrid sudan grass, a pasture sorghum, also could be produced in this way. An additional refinement, which can be introduced if it is wished, is to use a non-restorer male parent so that the hybrid will be male-sterile and thus, if grown by itself, also seed-sterile. This hybrid could be used for producing an all-forage crop (91).

Development of hybrid forage and pasture sorghums has not progressed as far as that of hybrid grain sorghums, but there seems to be no reason why they should not be used extensively in the near future.

Cytoplasmic Male-sterile Wheat

Corn and sorghum, two of the three major grain crops in the United States, now are hybridized commercially by means of cytoplasmic pollen sterility. Wheat (*Triticum* spp.), perhaps the most important of the three major grain crops, is not hybridized at all on a field scale. All wheat varieties grown are essentially inbred lines, albeit remarkably vigorous ones. There do exist, however, cytoplasms which will make some of the common wheats completely pollen sterile. Genes also have been discovered which will restore the pollen fertility of the cytoplasmic sterile wheats.

Origins. Kihara (63) has reported that the *Triticum vulgare* Vill. (*T. aestivum* L.) genome in *Aegilops caudata* L. cytoplasm is pollen sterile. A gene linked with or identical with that for black ear (derived from the *caudata* genome) will restore pollen fertility up to 70%. Fukasawa has reported that male-sterility appears when the genome of *T. durum* Desf. var. *Reichenbachii* is put in the cytoplasm of *Aegilops ovata* L. The pollen-sterile *durum* gave pollen-sterile F_1 hybrids when crossed as female to eleven Emmer wheats (each with the same AABB genome as *durum*); but when crossed to a twelfth, T. *dicoccioides* Korn. var. *Kotschyanum*, the F_1 had about 80% fertile pollen. When one *ovata* chromosome was added to a complete *durum* genome in *ovata* cytoplasm, the plant was pollen fertile. Fukasawa concluded that the *ovata* chromosome contained a fertility-restorer factor which was lacking in the *durum* genome (31, 32, 34, 35, 37).

Obstacles To Commercial Application. Superficially then it looks as though in wheat there are all the requirements for producing hybrids by means of the cytoplasmic male-sterility method; i.e., sterile cytoplasm and fertility-restorer genes. Actually, there are several special problems which may well be insurmountable. The most important of these is the fact that wheat pollen is thought to be viable in the air for only a short time (38, 108). Wheat normally is highly self-pollinated, but the pollen can be carried by the wind. It may be that a cytoplasmically male-sterile wheat, even if planted close to a pollen fertile wheat, would set very little seed because little viable pollen had reached the stigmas of the male-sterile wheat. In at least one experiment this was the result (38). On the other hand, data reviewed by Hayes, Immer, and Smith (44) indicate that emasculated or self-sterile wheat can often make relatively large amounts of seed under conditions of natural cross pollination. Possibly selective breeding, or proper choice of environments, could improve the ability of wheats to open-pollinate.

It may be that wheat hybrids will not have enough extra yield to be worth the trouble. E. R. Sears has stated that the best hybrids reported have shown only 10-15% improvement over their parents (108). Many hybrids show no yield increase at all. It is true of course that extra yield is only one advantage of hybridization. Disease resistance and desirable agronomic factors often can be incorporated into hybrids more conveniently than into a single inbred line. By changing combinations of inbreds one can quickly change a hybrid variety to meet shifting demands, such as those created by variable populations of rust pathogens.

A further possible problem in making hybrid wheat might be some qualities conferred by the sterile cytoplasm itself. For instance, Fukasawa states that plants of *T. durum* in *Ae. ovata* cytoplasm are shorter, have smaller leaves, and mature later than *T. durum* plants in their own cytoplasm. The male-sterile plant also has a chlorophyll abnormality in the winter growing period (33, 36). Changes such as this, other than the chlorophyll abnormality, might not necessarily be disadvantageous, of course, if one were not aiming to duplicate exactly a hybrid as it would appear in normal cytoplasm.

At least one wheat breeder, B. C. Jenkins of the University of Manitoba, is investigating the possibilities for producing hybrid wheat by means of cytoplasmic pollen sterility, although he says that his work at the moment is only in an exploratory stage (47). At the present time he is developing some cytoplasmic male-sterile varieties to test the amount of natural crossing.

Possible Cytoplasmic Male-sterility in Rice

Another of the world's great cereal crops, rice (*Oryza sativa* L.), may have in it sources of cytoplasmic male-sterility. Sampath and Mohanty (105) have reported that a difference in pollen sterility between reciprocal F_1 hybrids of *japonica* and *indica* varieties may be due to differences in cytoplasms. No further experimentation on this subject has been published as yet, although Sampath has stated in private communication (104) that Japanese workers have found that when the japonica genome is put in *indica* cytoplasm the semisterility exhibited by the original F_1 cross is continued.

Cytoplasmic Male-sterility in Pearl Millet

Burton (11) described a case of cytoplasmic male-sterility in the southern forage grass, pearl millet (*Pennisetum glaucum* L.). It was discovered in somewhat the same fashion as was related above for sorghum. In this case, the sterility-inducing cytoplasm was contributed by an inbred strain (inbred 556) known to be partially male-sterile, but which can be maintained by selfing. It was found that some plants in the F_2 of the hybrid: inbred 556 x inbred 23, were male-sterile.

When these male-sterile plants were backcrossed as female to inbred 23, all plants of the backcross also were male-sterile. Burton then crossed the male-sterile backcross plants to several other inbred lines and found that six crosses were male-sterile, eight were partially male-sterile and 27 were completely male-fertile, indicating a diversity among millet inbreds with regard to their sterilizability in 556 cytoplasm. It appears that the cytoplasmic male-sterility in millet resembles that in many other species in that the contribution from the cytoplasm can be overcome by dominant fertility-restorer genes. The complexity of the genetic contribution has not yet been completely determined, although it appears that restoration may be due to a single dominant gene, plus modifiers (12).

Burton suggested that this cytoplasmic male-sterility could be used to produce hybrid millet seed in the form of single crosses. He stated, incidentally, that fertility restoration would not be needed for countries like the United States where the grass is grown only for forage. A male-sterile hybrid would prevent the farmer from growing F_2 seed, with resultant yield loss, and the seed sterility also would help maintain the grass in a vegetative condition. Work is now in progress to exploit the 556 cytoplasmic male-sterility for production of hybrid pearl millet seed (12).

Orchard Grass

In 1946 Myers (74) reported a case of cytoplasmic male-sterility in orchard grass (*Dactylis glomerata* L.). Sterility appeared to be caused by the interaction of a specific cytoplasm with at least one dominant gene. Due to polyploidy the gene could be present in more than two doses; so the segregations were more complex than would be the case in a diploid organism. To date, this male-sterility has not been exploited for making hybrid orchard grass, largely because further experimentation indicated that the genetics was so complicated that the sterility could not be conveniently utilized (75). However, if a sufficiently simple cytoplasmic sterility (genetically speaking) can be found, it is thought that hybrid orchard grass seed production would be commercially feasible.

Cytoplasmic Sterility for Hybridizing Peppers

The common pepper (*Capsicum frutescens* L.) is another crop plant in which cytoplasmic male-sterility has recently been found. Peterson discovered a male-sterile plant in a Bureau of Plant Industry accession in 1953. He has shown (89) that its sterility was due to an interaction between its cytoplasm (S) and at least one recessive gene. There is evidence for a second non-linked gene which also can cause sterility when homozygous recessive in S cytoplasm. These genes have no effect on sterility when in N cytoplasm, the cytoplasm normally present in all other types of peppers which Peterson has tested. The S cytoplasm appears to have remained perfectly stable with respect to pollen fertility through five generations of testing. It appears that modifiers can affect the degree of sterility, for pepper varieties seem to vary in the degree to which they can be sterilized. It also was found that environment modified the expression of sterility. Plants which were sterile in the field could shed viable pollen during the winter in the greenhouse. In the greenhouse Peterson was able to duplicate the summer sterility of genetically sterile plants by subjecting them to high temperatures and continuous illumination for a two-week period. Normal fertiles maintained their fertility under this same treatment. The positive correlation of sterility with temperature resembles that apparently shown by corn and is the reverse of that shown by sorghum and onions.

Much interest in pepper cytoplasmic male-sterility has been shown by breeders both in academic and in commercial fields,

and several breeders already are working with it (90). Most pepper varieties are highly variable in almost all characters of economic importance. Even if no yield advantage could be shown for pepper hybrids, the uniformity which they could give might alone make hybrids well worth while.

Cytoplasmic Male-sterile Carrots

Origin and Inheritance. In 1947 Welch and Grimball (122) reported that a male-sterile carrot (*Daucus carota* L. var. *sativa* DC.) had been found in the commercial variety "Tendersweet". The mode of inheritance of the male-sterility was not known at the time of publication. Subsequent study of this character has revealed that it is cytoplasmic, although like all cytoplasmic steriles mentioned in this article, expression of the sterility also is governed by the nucleus (39, 121). The nuclear factors are different from those noted above for other crops, except orchard grass, however, in that the gene for sterility is dominant, not recessive. In many instances cytoplasmic sterility of the carrot seems to be governed simply by one gene, but several cases have been reported in which ratios vary significantly from that expected for a single gene. Much is yet to be learned about the genetics of cytoplasmic sterility in the carrot.

Utilization. Carrot hybrids show considerable vigor, and hybridization seems to be well worth the trouble. Interest in carrot hybrids developed slowly at first, but since 1956 seedsmen have been highly interested in the possibilities. To date no hybrid carrot seed has been produced in commercial quantities (40, 121). In Europe, breeding programs with cytoplasmic sterile carrots have been started in England (43) and in the Netherlands (3) but are only in early stages of development.

New Sterile Cytoplasms. Several government and university breeders are working with cytoplasmic sterile carrots. They have found several new sources of S cytoplasm (121) so that now at least a dozen different sources are known. Breeders are in the process of comparing these cytoplasms to the original discovery. Most of them seem to be the same as the original with the possible exception of one stock which appears to be relatively unstable. Several new sterile cytoplasms have been discovered in local carrot varieties in the Netherlands, also (3).

Potatoes and Cytoplasmic Male-sterility

In at least one genus, the cytoplasmic male-sterility which has been recorded quite certainly will not be utilized for large-scale production of hybrid seed. Differences in pollen sterility between the reciprocal F_1 hybrids of *Solanum tuberosum* L. (the Irish potato) and *S. acaule* were attributed by Lamm (66) to an interaction between *tuberosum* cytoplasm and one or more *acaule* genes.

Since potatoes are grown from tubers rather than seed, it is apparent that, even if a cheap method for mass hybridization of potatoes could be developed, there would be no market for the product. The phenomenon can be useful, however, for production of experimental hybrids.

Sugar Cane

Sugar cane (*Saccharum* spp.) also is reproduced by vegetative cuttings, and the market for its seed is nil. Cytoplasmic male-sterility tentatively has been reported in the sugar cane genus, however (93). When *Saccharum spontaneum* L. is crossed to several other species of the genus (including *S. officinarum* L., the common sugar cane), the F_1 is male-sterile if *spontaneum* is used as female, but fertile if it is used as male. A backcross of *S. spontaneum* x *S. Sclerostachya* to *S. Sclerostachya* gave both male-sterile and pollen-fertile individuals, indicating a segregation of nuclear factors which have effect on pollen fertility when in *S. spontaneum* cytoplasm.

Cytoplasmic Male-sterility "Made-to-order" in Petunia

Origin. Perhaps the best illustration of purposive plant breeding to produce cytoplasmic male-sterility is that of the production of cytoplasmic male-sterility in the common garden petunia (*Petunia hybrida* Vilm.). At the time D. F. Jones was doing his early work with cytoplasmic male-sterile corn, two of his graduate students, H. L. Everett and W. H. Gabelman, impressed with the fact that Clayton (14) had produced male-sterility in tobacco by means of genome transfer from the cytoplasm of one species into the cytoplasm of another, decided to try to duplicate his work, using petunia (30). Everett obtained several hybrids which had as the female parent some unidentified species of petunias (probably *P. axillaris, P. integrifolia* and-or *P. parodii*) (69). In all cases the male parent was a commercial variety or other *P. hybrida* material. These hybrids were further backcrossed to several name varieties of petunia, using the name varieties always as pollinators. In some of the backcross progenies, male-sterile progeny were obtained, and from these, cytoplasmic male-sterile petunia varieties were developed by means of continued back-crossing to the varieties (30).

Use. The original cytoplasmic sterile stocks have been widely disseminated among commercial petunia breeders and have been further backcrossed to many other petunia varieties. Several hybrid petunias now being sold are made with the aid of cytoplasmic male-sterility at a considerable saving in costs of hybridization. Not all of the handwork is eliminated by the use of male-sterility, however, for the actual cross-pollinations still are usually made by hand (41). Only the hand-emasculation has been eliminated. It is considered to be impractical to obtain proper isolation for field hybridization of petunias.

Problems. Petunia cytoplasmic male-sterility has been found to be influenced by the genotype (41) as has been true for all other cytoplasmic male-steriles discussed here. Some varieties, therefore, cannot be sterilized conveniently. Fertility restoration appears to be dominant and multigenic in its inheritance. The environment can modify the amount of sterility for some genotypes, although most of them are quite stable.

An interesting, although not commercially desirable, side effect of the sterility-inducing cytoplasm has been noted. It sometimes suppresses development of the entire flower of certain varieties of petunia, especially the grandiflora types (41, 111). The percentage of suppressed flower buds varies with variety and with environment. It has been found, however, that when some cytoplasmic male-sterile varieties with suppressed flower development ("blindness") are crossed with certain other pollen-fertile varieties, hybrids which have normal flowers are produced. On the other hand, some cytoplasmic sterile varieties with normal flower development will produce "blind" hybrids when crossed to certain other pollen-fertile varieties. Since environment affects expression of the "blindness", careful testing of cytoplasmic sterile hybrids is necessary prior to their release.

Despite these various difficulties, the use of cytoplasmic male sterility has become widespread in the petunia trade and seems to be growing in importance (41, 111). One advantage of cytoplasmic sterile hybrids has been that they tend to stay in bloom indefinitely and do not "seed themselves out of flower" as do some pollen-fertile varieties (41).

Flax Cytoplasmic Male-sterility Not Used

It is interesting to note that flax (*Linum usitatissimum*), the plant in which the first clear-cut case of cytoplasmic male-sterility was worked out, has not been hybridized commercially by means of the cytoplasmic male-sterility method.

Flax normally is self-pollinated, although insects occasionally carry pollen from one flower to another. It has been thought that the amount of cross-fertilization occurring under field conditions would be too small to make worthwhile the use of male-steriles for producing hybrid seed on a large scale (17). The attractiveness, to insects, of the flower on the cytoplasmic male-sterile strain studied by Bateson and others has been further reduced, presumably, due to the fact that the flowers had reduced petals. Since in *Nicotiana* and in *Solanum* (14, 64) it was possible to disassociate, by selection, cytoplasmic floral abnormalities from cytoplasmic male-sterility it seems that there may be possibilities (at least in theory) of breeding a male-sterile flax with normal petal development. It also may be pertinent to note here that Rick (99) has found that in the tomato, which normally is almost entirely self-pollinated under United States cultural conditions, the amount of insect cross-fertilization measured as seed yields of male-steriles compared to pollen-fertile checks went to as high as 47% under certain ecological conditions.

Tobacco

In the tobacco genus, cytoplasmic pollen sterility, due to an interaction between cytoplasm and genes, was reported in 1932 by East (26). It was caused by introducing the *Nicotiana Sanderae* Sander genome into the cytoplasm of *N. langsdorffii*. Fertility restoration appeared to be due to a single dominant gene. Clayton in 1950 (14) reported that when the genome of *N. tabacum* (the species used for production of smoking tobacco) was placed in the cytoplasm of either *N. debneyi* or *N. megalosiphon* male-sterility occurred. The male-sterile plants appeared to be identical with their normal cytoplasm counterparts except for a floral abnormality in the steriles which had *debneyi* cytoplasm. Seed production was normal when pollen was supplied.

To date, cytoplasmic sterility of *Nicotiana tabacum* has not been used to produce hybrid tobacco seed on any large scale (15, 51). This is largely because yield is not as important to the tobacco growers as are various quality characteristics of the leaf. The phenomenon is being tested, however, as a means to eliminate the necessity of topping (removal of the flowering top portions of the plant to prevent seed production) (51).

Pistillate Castorbeans

The castorbean plant (*Ricinus communis* L.) normally is monoecious. Genetic factors have been known for some time, however, which cause progeny to segregate pistillate as well as monoecious plants. It has been noted that some progenies have excessive numbers of pistillate plants. Suspecting that these unusual ratios might be evidence of something other than a purely genetic control, Parkey (87) isolated and sibpollinated several progenies from the variety "Custer" which showed an unusually high number of pistillate plants. When one of the resulting lines was crossed and backcrossed (as female) to several designated male (monoecious) parents, it was found that in some cases all the progeny were pistillate. Further breeding tests led Parkey to conclude that pistillate castorbeans result from combination of a specific cytoplasm with at least one dominant nuclear factor.

It was suggested by Parkey that the cytoplasmically controlled pistillate sex expression could be used to produce hybrid castorbean seed, but he noted that the general behavior of the phenomenon needed further study before its value could definitely be determined.

His caution appears to have been justified, for as backcrossing was continued it was found that, in addition to the expected all-pistillate progenies, some segregating and some entirely monoecious progenies were produced (109). It is not yet known whether these aberrent proge-

nies were the result of incorrect selection due to environmental modification of sex expression or whether some new explanation must be given for the results.

Possible Use of Cytoplasmic Differences to Effect Hybridization in Cabbage

Mizushima and Katsuo (73) have reported that, when the genome of the common cabbage (*Brassica oleracea L.*) is placed in the cytoplasm of *B. nigra*, the plants are self-compatible instead of self-incompatible as is the original cabbage male parent. The plants with *oleracea* genome in *nigra* cytoplasm can be crossed as male to *oleracea* in *oleracea* cytocytoplasm to give a self-incompatible hybrid; but when the reciprocal cross is made, the resulting hybrid is self-compatible.

Mizushima is considering the possibility of using this phenomenon to make hybrid cabbage, by using *nigra* cytoplasm to maintain an *oleracea* inbred by means of selfing and at the same time backcrossing this inbred into *oleracea cytoplasm* to give a self-incompatible inbred line. This self-incompatible line then could be crossed, as female without emasculation, to other suitable lines in order to produce hybrid cabbage. The general plan of operation thus would be about the same as that for handling cytoplasmic male-steriles. He also has considered using this stock for hybridization or for other breeding projects with other *B. oleracea* varieties such as kale, Brussels sprouts, cauliflower, etc. (72).

The notion of cytoplasmically-induced differences in regard to self-incompatibility is one which seems to be entirely new. It may be that a survey of cytoplasmic effects on self-incompatibility genes of other species may open the door to an entirely new field of hybridization possibilities. Anyone who has worked with cytoplasmic male-steriles will recognize that it would be extremely convenient to be able to make certain pollinations with the cytoplasmic male-sterile individuals, in the course of breeding projects. This, in effect, is possible with cytoplasmically-controlled self-incompatibility, since the pollen of the self-incompatible strain (the counterpart of the male-sterile) will operate perfectly well on the stigmas of appropriate genotypes.

Conclusions

This list of crops in which cytoplasmic male-sterility is used to effect large-scale hybridization probably is out of date even as it is written; for interest in this method now is widespread, and breeders today are saving and testing male-sterile plants of nearly every crop which is propagated by seed, to see whether or not the sterility is cytoplasmic in nature. The list of species in which cytoplasmic male-sterility has been discovered increases each year.

There are, of course, some plants which cannot or need not be hybridized by means of the cytoplasmic male-sterile method. Among those species which are propagated vegetatively there is no need of any method for controlled mass hybridization, for any superior hybrid can be disseminated as parts of the same clone. Some plants ordinarily cannot be cross-pollinated either by insects or by the wind, due to timing of anthesis, flower shape, pollen characteristics, etc. Unless these plants can be rebred so that the flower type is accessible and desirable to insects, or so that their pollen remains viable in the air for a longer period of time, etc., they are not susceptible to successful mass cross-pollination. In some crops the amount of vigor exhibited by hybrids is considered to be too little to make hybridization worth while, although it would seem that such conclusions should not be reached too quickly if one does have at hand an economical method for large-scale hybridization of the crop in question. Also, sometimes the uniformity which hybridization can make possible is more valuable than any yield increase it might give. Some crops are produced on such

a small scale, or have quality requirements which are so low, that the expense and time of a breeding program to make hybrids by means of cytoplasmic male-sterility would not be warranted. And, finally, some crops have a sufficiently favorable ratio between price of seed and cost of hand-emasculation so that it is economically feasible to produce hybrid seed without the use of cytoplasmic sterility, although in such cases cytoplasmic male-sterility would usually be a welcome, even though not an essential, refinement.

It seems probable that there are few species in which cytoplasmic male-sterility cannot be found if proper search is made. It is pertinent to note that, once a case of cytoplasmic male-sterility has been found in a species, breeders have then often been able to find or produce additional cytoplasmic steriles in the same species (note above, corn, sugar beets, wheat, carrots, tobacco, onions). In addition to testing chance discoveries of male-sterile individuals, a systematic program of genome substitution, either among varieties of a species or among species of a genus or even of related genera, probably would often more than repay its cost if there were a real need for a source of cytoplasmic sterility in any given crop plant.

There seems to be too little study of the fundamental genetics of cytoplasmic male-sterility of most of the crops in which it now is known. The usual pattern has been for a few pioneering papers to appear, which made it clear that cytoplasmic male-sterility probably was of economic value for the crop studied, followed by much energetic work aimed at economic exploitation, with few or no further published accounts of basic studies of the phenomenon. This is undesirable from the point of view of fundamental genetics, and it also is economically undesirable; for, as has been said in many places recently, without concomitant, published fundamental research the application of original studies will proceed in inefficient fashion and eventually may wither on the vine. Fortunately, the pattern just described is not true universally, and in a few instances some promising basic studies of cytoplasmic male-sterility are being carried out. Let us hope that the number of such studies will increase.

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The Utilization of Mustards

The best known usage of members of the mustard group is as the basis for condiment, but some of the species are important as oil seeds. The leaves are widely used as a vegetable, especially in the Far East, while in temperate agriculture mustards are extensively used as green manures, cover crops, and fodder. Oilcake residues after expressing are used as fertilizers.

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Introduction

According to Musil (15), *Brassica* species of commercial importance can be divided into rapes, cabbages, and mustards. Musil includes in the group of mustards: (a) turnips and turnip-rapes; (b) black mustard; (c) white mustard; (d) Indian or brown mustard; (e) oriental or Chinese mustard; and (f) charlock. The present paper refers mainly to the utilization of the last five types of mustard, although some account is also given of *Eruca sativa* Lam.

The term "mustard" is believed to be derived from the usage of seeds as condiment; the sweet must of old wine was mixed with crushed seeds to form a paste, "mustum ardens" (hot must), hence "mustard".

The following are the main species of economic importance:

Black Mustard *(Brassica nigra* (L.) Koch). The plant is widespread in Central and Southern Europe and most regions with a temperate climate. The original home of the species seems to be unknown, but it has been suggested (25) that the plant belongs to a Mediterranean center with a secondary center in the Near East.

In commerce the seeds of the plant are utilized for condiment and for oil, while in agriculture, *B. nigra* has occasionally been planted as a cover crop. It has been cultivated for its seed particularly in Holland, England, Italy, Hungary, Austria, Roumania, Bulgaria, France, Greece, Russia, Syria, India, China, North Africa, Chile, Australia, New Zealand, Argentina, and the U.S.A. In England (17) it is grown in deep, rich, fertile soil in the eastern counties, being sown in the spring and harvested in August, when it is cut rather green and allowed to ripen in small carefully made stacks. Well known commercial varieties of the seed are English, Bari, Trieste, and Californian.

White Mustard *(Sinapis alba* L.). This mustard is probably a native of the Mediterranean and the Near East but has been introduced into northwestern Europe, Russia, Japan, North and South America, Australia, New Zealand, India, North Africa, and China.

Like black mustard, its seeds provide oil and are used as a condiment. The plant is grown for its seed in various parts of Europe and America, particularly England, Austria, Czechoslovakia, Sweden, Holland, Russia, France, Germany, Australia, Argentina, and California.

White mustard is also used as a salad plant, a green fodder crop, and a green manure.

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Indian or Brown Mustard (*Brassica juncea* Coss. and Czern.). Burkill (2) has given an admirable account of the development of nomenclature and extent of this difficult species. He points out that, like *B. nigra,* it is a pungent mustard, but it is more nearly tropical than the *nigra* species, and, consequently, stands heat better and is fairly drought-resistant. He suggests that for backward agricultural communities it offers the advantage over *B. campestris* L. of being disliked, on account of its pungency, by various pests which the communities do not control.

Burkill is of the opinion that *Brassica juncea* is an Old World plant, at home in the rather dry parts of North and Central Africa, the Levant, the North of India and probably the interior of China. It is now to be found in many parts of America, Europe, Asia, and Africa. He believes that human agency has played a large part in this dispersal and has suggested the carrying of *B. juncea* to the West Indies by negro slaves from Africa. The Chinese might well have carried the plant to Malaya, while the appearance of *B. juncea* near European ports indicates a connection with imported grain. Vavilov (24) records the primary center of origin of the species as central Asia (northwest India, including the Punjab and Kashmir) with secondary centers in central and western China, Hindustan (east India and Burma) and Asia Minor through Iran.

The plant has mainly been developed for oil and as a vegetable but in the last decade has become important in the condiment industry as it is an easier crop to grow than *Brassica nigra* (16). It has also been used in some countries as a cover crop. Well known cultivated races of the species are Asl-rai or Indian mustard, Sarepta mustard (*B. besseriana* Andr.), Palai rape (*B. rugosa* Prain), and Abyssinian mustard (*B. carinata* A. Br.).

Oriental or Chinese Mustards (*Brassica pekinensis* (Lour.) Rupr., *B. chinensis* L., and *B. perviridis* Bailey). Petsai (*B. pekinensis*), pak choi (*B. chinensis*), and tendergreen (*B. perviridis*) are salad and vegetable plants with a probable origin in China and Japan. They have been introduced into and appear to be popular in Canada and the U.S.A. The first two species have been cultivated in France and are offered for sale by specialist seed merchants in Great Britain.

Charlock (*Sinapis arvensis* L.). Charlock is found in Europe, North Africa, South West Asia, Russia, North and South America, South Africa, Australia, and New Zealand. It is best known as a very persistent weed of arable land in temperate agriculture, with seed viabilities of up to 70 years, but it is cultivated to a small extent for oil seeds in south Russia, France, Hungary, and Roumania. Charlock has also been used as a vegetable, a cover crop, and an adulterant of poor quality table mustard.

Rocket (*Eruca sativa* Lam.). This plant seems to be of Mediterranean and East Asian origin but is now found in many other parts of the world. It has been cultivated in France, Spain, Persia, and India, and its cultivation dates back to ancient Greek and Roman times. Rocket has been utilized as a salad plant while its seeds have provided oil and have been used as a condiment.

Condiment

The types of mustard seed usually utilized in the preparation of fine table mustard at present are *Brassica juncea* and *Sinapis alba.* In the past *B. nigra* was the species of brown mustard used with *S. alba. B. juncea* seed was first imported into France from Russia and India about 1860 (18), but little was used in good quality condiment mustard until after the Second World War. Since that time *B. juncea* has gradually replaced

B. nigra as it is preferred as a crop by farmers and can be grown more economically.

Mustard condiment has long been of importance, and there are numerous references through the centuries to its usage and properties. Pliny gave an account of its medicinal virtues, while Pythagoras recommends it for scorpion stings and the Romans are believed to have been responsible for the spread of *S. alba* throughout Europe. Nicholas Culpepper, the 17th century English scientist, recorded some of the superstitious beliefs in the efficiency of mustard "for clarifying the blood and for weak stomachs, for strengthening the heart and resisting poisons, and for drawing out splinters of bones". The Greeks used mustard for sauce with fish, and in Chaucer's time it was commonly used with meat dishes. Mustard was among the stores carried by Vasco da Gama on his first voyage around the Cape of Good Hope in 1497.

John Wycliffe, in the 14th century, refers to an early prepared mustard, probably composed of roughly crushed seeds stored in vinegar. The earliest English center for the production of such prepared mustard was Tewkesbury, from whence balls of mustard paste were sent to London during the 17th century. Shakespeare makes Falstaff say, "His wit is as thick as Tewkesbury mustard". The practice of fine grinding and sifting of mustard flour was first started by a Mrs. Clements in Durham (1720), and this lady is said to have had considerable custom from George I. Powder mustard rapidly increased in popularity during the 19th century with the center of production at Norwich in England. The French centers of Dijon, Bordeaux, and Toulouse have specialized in the production of paste mustards.

Nowadays mustard condiment is marketed in two forms. In Great Britain, North America, and most of the British Commonwealth both powder and paste mustards are sold, whereas in France, the rest of Europe, South America, and other parts of the world the demand is almost exclusively for paste mustards, and very little powder mustard is sold. Powder mustard consists usually of a mixture of mustard flours to which may be added wheat flour. Mustard paste, also known as French or German mustard, is a mixture of flour or ground seed of one or more kinds of mustard with spices, salt, and vinegar. Poor quality mustards are sometimes adulterated with charlock, starchy matter, mustard hulls, gypsum, and other mineral substances, dyes and preservatives (27). Campbell (4) has given a number of recipes for table mustard.

Both black and white mustard seeds contain relatively high proportions of fixed oil, protein, and carbohydrate, but the use of mustard as a condiment is mainly related to the pungent principles of the seed. Black mustard contains the glucoside sinigrin, while in white mustard the glucoside is sinalbin. Both mustards have the enzyme myrosin which is to be found in cells different from those that contain the glucoside, and therefore no reaction takes place unless the seeds are crushed and then moistened. The pungent principle produced as a result of the reaction between myrosin and sinigrin is the volatile allyl isothiocyanate, which in the condiment produces heat in the throat and nose. The amount of allyl isothiocyanate produced varies within the species. Juillet, Susplugas, and Courp (12) have given a whole range of percentage production of the volatile oil from 0.59 in Hungarian seed to 1.26 in Chilean seed. In white mustard the essential principle is parahydroxybenzyl isothiocyanate. This substance is not volatile in steam but gives a "hot" flavor to the palate.

The position in *Brassica juncea* is not clear. It is usually stated (12) that the volatile mustard oil is a mixture of allyl isothiocyanate and crotonyl isothiocyanate. Again, there is variation within the species. The percentage production of

allyl isothiocyanate is said to vary between 0.33 and 0.44 and of crotonyl isothiocyanate between 0.27 and 0.36. However, Schmalfers and Mueller (22) deny the existence of crotonyl isothiocyanate in the volatile mustard oil prepared from a sample of Sarepta mustard. It may well be that the wide variation within the species is attributable to its origin as an amphidiploid hybrid between *B. nigra* and *B. campestris* (9) the pungent principles of which are respectively allyl- and crotonyl-isothiocyanate. Current research programs in France and England are aimed at the selection of strains of *B. juncea* with high contents of allyl isothiocyanate.

Charlock (27) produces practically no volatile principle, while in *Eruca* (12) the percentage production varies between 0.5 and 0.6%. In India Pahadi rape or Palai rape *(B. rugosa)* is crushed and used as condiment (21).

In Great Britain (26) brown mustards are not grown for forage but are widely cultivated for seed in Cambridgeshire, Norfolk, and Lincolnshire and adjoining counties with production chiefly on contract for condiment manufacture. In the past the common variety of *B. nigra* was "English Brown" which yielded some eight or nine cwt. of clean seed per acre; but as the plants shed seed badly when maturing, the crop demanded careful hand harvesting. A variety of *B. juncea* known as "Trowse" is now grown. It yields from seven to twelve cwts. per acre; and as the plants hold their seed well, the crop can be harvested by combine harvester. White mustard is grown for seed in the same areas of Great Britain; the crop is cut and swathed to dry and then either stacked before threshing or picked up and threshed by a combine harvester. The yield of white mustard ranges from seven to ten cwts. per acre.

The total acreages of mustard under cultivation in Great Britain are shown in Table I.

TABLE I

MUSTARD ACREAGES IN GREAT BRITAIN (29)

Year	Acreage of mustard for seed*	Acreage of mustard for fodder and ploughing in*
1934	16,900	.....
1935	28,447	20,219
1936	31,920	23,820
1937	24,154	22,369
1938	23,703	26,914
1939	23,551	24,292
1940	24,146	29,605
1941	17,285	27,700
1942	21,544	26,520
1943	15,933	29,507
1944	12,518	28,977
1945	18,083	23,944
1946	24,974	21,644
1947	35,847	24,644
1948	16,577	21,292
1949	14,749	21,663
1950	28,186	
1951	58,924	
1952	42,106	
1953	37,968	
1954	33,637	
1955	39,658	
1956	31,518	

* The "acreage of mustard for seed" includes both white and brown mustard (*Brassica nigra* up to 1952 but principally *Brassica juncea* since that year), whereas the "acreage of mustard for fodder and ploughing in" is almost exclusively white mustard.

The annual seed production of white and brown *(B. nigra)* mustard in Great Britain varied from 3,000 to 14,000 tons between 1934 and 1949, with annual values ranging from £276,000 to £700,000 (29).

After the mustard seeds are harvested, it is essential that they are dried at an early stage to prevent the growth of moulds. In Great Britain they are roughly dried on the farm, and the process is completed at the factory. The maximum temperature for drying is 115°F. Large stocks of seed are usually held in order to insure a regular supply for milling.

The milling process is essentially the separation of the bran (testa and aleurone layer) from the flour (embryo and cotyledons). This is effected by variously shaped rollers. The flour is then subjected to careful sifting to separate the fine and coarse fractions. This sifted flour

constitutes, in part, powder mustard, although it is usually possible to pick out a number of testa fragments. In England no fixed oil is removed from the mustard seed prior to milling. This is not the case, however, in the rest of Europe and in America, where the seeds are often partially de-oleated by crushing to aid the milling process.

Apart from its use as a condiment, mustard flour and its by-products have been employed in many other spheres. The utilization of the mustard fixed oils and the seed residues as feeding stuffs or fertilizers is important but will be referred to at a later stage in this article.

Mustard is incorporated in various food products such as salad creams, mayonnaise, sauces, pickles, piccalilli, and curries. It acts as a preservative against the action of yeasts and moulds. The pungent principles are responsible for this action, and mustard is said to be more efficient in this respect than sulphur dioxide and benzoic acid (7). A further quality of mustard in creams and mayonnaise is that it is a very efficient emulsifying agent (6).

Mustard has been used in the wine industry in France and Spain to remove mustiness in wine and wine barrels. It has also been used to prevent secondary fermentation in wine which would lead to bad flavor. A similar preservative action has been suggested for allyl mustard oil, or its equivalent in ground mustard, in fresh apple cider and fruit juices (10). Guenther (10) states that most of the "allyl mustard oil" offered on the market today consists of the synthetic product, the natural oil having lost much of its former importance.

In the field of medicine, mustard has been used to a certain extent. It has been employed as an irritant drug in the form of mustard baths, poultices, and plasters. As far as one can make out, this usage was largely domestic in Great Britain, and the general impression is that it is now very much on the decline. Mustard has also been used as an emetic and as a constituent of cough cures (20).

Oil

The fixed oils of the seed of various species of mustard are of definite economic importance.

Brassica nigra. The fixed oil of this species, obtained by expression, is brownish yellow and has a mild taste. Its content in the seed varies between about 26% and 37% (27). At one time it appears to have been a by-product of the allyl mustard oil industry. It has been used as a salad oil, for cooking, as a lubricant, a lamp oil, and in soap-making.

In Great Britain today this oil seems to be available only as a by-product of the condiment industry. Under these circumstances, it is generally sold for lubrication purposes.

At the present time, there is little crushing of any mustard for its fixed oil in Great Britain. The oil contents are lower than those of rape seed, and the "hot" nature of the seed residue usually precludes its use as a feeding stuff.

Sinapis alba. The oil is usually of a golden yellow color and has a mild taste. Its content in the seed varies between about 20% and 35%. It has been used as a lubricant and an illuminant.

At the beginning of the Second World War, Sweden became an important producer of oilseed crops (1). White mustard was cultivated because of its rapid growth. In 1951 the manufactured output of oil of this plant was 27% of the tonnage of seed harvested. White mustard oil has been used in Sweden in the production of mayonnaise. Cultivation of *S. alba* has, however, decreased in Sweden in recent years from about 16,000 harvested hectares in 1953 to about 5,000 hectares in 1957. In recent years *S. alba* has been grown on an increasing scale in Canada for oil production.

White mustard oil is also a by-product of the condiment industry in countries where the seed is partially deoleated before milling.

Brassica juncea. "Mustard oil" is one of the major edible oils of India, but it is a term that is applied loosely in that country to the fixed oils of Rai *(B. juncea)*, Toria *(Brassica napus* L. var. *dichotoma* Prain), and Sarson *(Brassica campestris* L. var. *sarson* Prain). *B. juncea* only will be considered in this article.

Rai is mainly cultivated in Bengal and Bihar (21). Varieties of the plant recognized in India are Laha, Lahi, Lahta, and Desi Rai, but breeding work has produced more uniform strains such as "R.T. 11" and "Raya 2.8" (28). Sowing takes place usually in October or November and harvesting in February or April. In India, *B. juncea* may be cultivated with peas and barley. Under these circumstances three pounds of the mustard seed are sown per acre, whereas for a pure crop four to six pounds of seed are sown per acre. The seed yield is in the region of 11 cwt. per acre.

Rai is mostly grown as a rainfed crop. It is said to be less susceptible to insect pests and diseases than other Indian *Brassicae* (28).

The plant is generally harvested before the fruits are completely ripe to preclude "shattering" (21). Night moisture helps to prevent shattering; hence, harvesting is usually carried out in the early hours of the morning. Entire plants are either pulled out by hand or cut a few inches from the ground with sickles. The plants are tied into small sheaves and dried in the sun for four to ten days. Harvesting, threshing, and winnowing are carried out by the cultivator and his family.

The fixed oil content of Rai seed varies between 28.6 and 45.7%. Extraction of this oil is carried out by village "ghanis," rotary mills, expeller and hydraulic processes. It is used mainly for culinary purposes. In the northeastern region of India the oil is used in its crude form as a frying medium for several food preparations. The oil is also utilized for massaging the body, as a hair oil, an illuminant, and a lubricant.

Brassica juncea is being increasingly grown as an oil crop in many other parts of the world. The race of the plant obtained from South Russia and Roumania is generally known as *B. besseriana* Andr. The adoption of this mustard as an oil crop is said to date from the end of the 18th century (2). It is stated that in Russia the oil of *B. besseriana* is used in place of olive oil (28). Two forms of *B. juncea* are cultivated in the U.S.A. and Canada. The brown-seeded type is probably *B. besseriana* (15). The yellow-seeded form, probably of Chinese origin, is known as Oriental or McCormick mustard (15). In the U.S.A. Montana is the largest mustard-producing state (13). The oil is expressed as a preliminary step in the making of food products and has been used as a special lubricant in the place of rape oil (13). Alberta is the principal mustard-growing region of Canada, and in 1956 over 87,000 acres were seeded to *B. juncea*. Most of the crop was exported to Europe, but a small amount was used locally for expressing or condiment manufacture.

Brassica carinata is usually regarded as a race of *B. juncea* (23). The seed is now frequently found in European commerce under the name of Ethiopian rapeseed. In Ethiopia the plant is cultivated on small lots, and in 1956 exports of the seed amounted to some 8,000 tons. Analyses of *B. carinata* seed crushed in Great Britain give fixed oil contents of between 35% and 38%.

Sinapis arvensis. Charlock seed contains about 26% fixed oil (27) which has been used for soap making, cooking, and lubrication. This seed has been imported into Great Britain and France from Russia and Roumania under the name of Ravison, although the commercial material contained many seed impurities, such as *Brassica campestris, Camelina,*

and *Lepidium* (3). Of recent years Ravison has not been crushed in Great Britain.

Charlock seed, separated from cereal crop screenings, has been utilized for its oil in the U.S.A. and Canada (8).

Eruca sativa. The seed of this plant is utilized for its oil mainly in India where it is known as Jamba or Taramira. It is grown extensively in the Punjab. The fixed oil content varies between 32% and 36% (21).

An important commercial aspect of the crushing of any oil seed is the disposal of the seed residue. Mustard meals are comparatively rich in protein, but their pungent principles normally make them unsuitable for stock feed purposes.

Brassica nigra and *B. juncea* cake are usually considered unsuitable for feeding cattle (12) because of the production of allyl isothiocyanate in the cake remaining after the oil has been extracted by expelling. Indian rape and mustard cakes are treated with some caution in Europe (3) because of the possible presence of *B. juncea,* although the cake of the yellow-seeded *B. juncea* of Montana (13) has been used in stock feeds there, but its content is kept below 5%. If a solvent extraction of *B. nigra* or *B. juncea* oil has been used, followed by steam treatment, there should be no residue of allyl isothiocyanate, and the cake so prepared is innocuous.

White mustard and charlock (Ravison) seed residues are also considered unsuitable for feeding. The pungent principle of white mustard has been described in a previous paragraph. It is suggested (12) that the toxicity of charlock meal is due to choline and sinapic acid, derivatives of sinalbin.

All the residues described can be used as fertilizers, but the commercial value of a meal used as a fertilizer is very much less than if it is used as a feeding stuff. In Great Britain, at least, this is one important reason for the small amount of mustard seed crushing for oil.

In contrast to other mustards under consideration, *Eruca sativa* cake is well thought of as a feeding material. In India, particularly in the Uttar Pradesh and Punjab provinces, it is given to cattle, camels, and horses (21).

Other Uses of Mustard

Most of the species of mustard described are used as vegetables, often in the raw state.

Brassica juncea is cultivated in many parts of the world as a vegetable and salad plant. *B. juncea* var. *cuneifolia* or Mustard Vegetable is cultivated in North Bengal and Assam as a pot herb, while *B. rugosa* or Cabbage Leaved Mustard is common in Nepal where the leaves are dried in the sun, pickled, and eaten (28). *B. carinata* is grown all over the highlands of Eritrea and Ethiopia in small fields near villages and homesteads. The plant is grown mainly for its tender leaves and sprouts which are boiled and eaten especially during periods of fasting which are numerous among the Coptic people. *B. juncea* is used considerably as a vegetable from wild sources or in the nearly wild condition in certain parts of West Africa (2).

In the U.S.A. and Canada and in Holland *Brassica juncea* seems to be grown to a considerable extent for greens. A large number of horticultural varieties or strains are in existence, and they would appear to be of Japanese or Chinese stock (14, 15). *B. juncea* has been introduced as a vegetable by the Chinese into Malaya and is known as "sawi hitam" (2).

The three oriental mustards *(Brassica pekinensis, B. chinensis,* and *B. perviridis)* are of importance in China and Japan but have also been introduced with success into other countries. In the U.S.A. *B. pekinensis* is a fairly common vegetable in the stores, although it is not often grown in the home garden. *B. perviridis* is not often seen for sale in

the northern states, although it is probably grown to some extent in home gardens. It is possibly more common in the South. *B. chinensis* seems to be grown only by Chinese market gardeners in the U.S.A. A similar state of affairs exists in Canada (14).

White mustard seed is sold together with cress (*Lepidium sativum* L.) in Great Britain and America for the production of seedlings used as "mustard and cress" in salads and sandwiches.

Young plants of charlock have been cooked as vegetables (11) while *Eruca* has been used as a salad plant both in southern Europe and the drier parts of the Old World tropics (5).

Because of their rapid growth mustards are widely used as cover crops and green manures. Black, brown, and white mustard are all used in America for this purpose (15), but in Great Britain white mustard is usually preferred. On good land *Sinapis alba* may attain a height of over two feet in less than two months (26) even when sown after an early crop has been removed from the field. The cover crop gives good protection to the soil between an early crop and a late autumn cereal sowing and is also in favor as it provides good cover for game birds on the farm. White mustard cover crops are sometimes grazed off as sheep fodder, but they are not suitable for dairy cattle as the strong flavor may taint the milk and milk products.

White mustard is extensively grown for ploughing in as a green manure when maximum growth has been reached. Apart from the value of the green manure in ameliorating soil structure and as a ready source of nitrogen, there is evidence (19) that white mustard is able to extract more phosphorus from soil minerals than many crop plants and so render it available to succeeding crops. The acreage of white mustard grown in Great Britain for fodder and ploughing in is shown in the foregoing table.

Because of their rapid growth and the ease of handling, mustards are frequently used as subject crops in experiments with herbicides and in soil culture studies on mineral deficiency or toxicity.

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BOOK REVIEWS

Abstract Bibliography of Fruit Breeding and Genetics to 1955. *Rubus* and *Ribes*—A Survey. R. S. Knight and Elizabeth Keep. Tech. Comm. No. 25, Commonwealth Bureau of Horticulture and Plantation Crops, East Malling, Maidstone, Kent, England. January, 1959. 45 shillings.

The survey covers currants, gooseberries, raspberries, blackberries, and hybrid berries, dealing largely with literature published between 1900 and 1955. The breeding, genetics, and cytology of *Rubus* and *Ribes* are summarized in detail, but pomological descriptions, the classification and synonymy of varieties and species, and diseases and pests are also covered. Gene lists and linkage data are given in appendices. Papers solely on the systematic botany of the two genera are given by title only.

DAVID J. ROGERS

Nomenclature of Plants. Harold St. John. The Ronald Press Co., New York. (Chronica Botanica. New Series.) 1958. $2.50.

This is a workbook for students of plant taxonomy. Problems for the application of appropriate scientific names are given, with all the necessary references to decide which name is to be applied. No solutions are given, as the author feels that if "the correct solution of each case is left freely open to each class, with the professor and students acting as judge and jury," there will be more learning of the various rules of nomenclature.

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Agriculture and Economic Development in India

The expansion in agricultural production is inevitable if India is to meet the food requirements of its increasing population. Today's utilization and consumption of the major economic crops, endeavors to improve these, and future needs are discussed.

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Introduction
Physical Factors and their Importance
The Structure and Problems of Indian Agriculture

Organization and Development of Agricultural Research

The Food-Producing Crops
- The Government and Food Production
- Cereals
- Legumes
- Subsidiary Foods
- Fruits and Vegetables

Commercial and Plantation Crops for Local Consumption
- Cotton
- Sugarcane
- Arecanut
- Copra
- Rubber

The Export Crops
- Beverage Crops
- Oilseeds
- Condiments and Spices
- Fiber Crops
- Essential Oils and Medicinal Crops
- Miscellaneous Crops
- Summary of Export Crops

The Government and Development
Summary and Conclusions
Bibliography

INTRODUCTION

There are archaeological, literary, and legendary evidences to show that agriculture has remained the principal economic occupation of India from time immemorial (52). From the earliest Vedic period (4000 B.C. to 2500 B.C.) to the end of the age of *Puranas*, the Indo-Aryans recorded in their scriptures, epics, edicts, and inscriptions numerous references to the various aspects of their agricultural activities. The economy of the people was so sound that the country was quite prosperous; and if the evidence of such foreign visitors as Megasthenes is to be believed, famines never occurred in those days. Even at present the agricultural sector contributes more than 50% of India's national income and is the means of livelihood of about 70% of the total population (24). Therefore, in any scheme of planned economic development of the country, agricultural reorganization and reform hold a position of basic importance.

There are many factors which have contributed to make the present Indian agricultural economy a complex one. The most important of these is the alarming rate of increase of the population. While the fertility rates are more or less constant, the mortality figures have steadily declined. This would naturally result in an even more rapid growth of numbers in the future than hitherto. The figure at the 1951 census stood at 356.88 million, and that estimated for 1960 is 408.05 million (11). Thus, one of the main problems in Indian agriculture is to find enough food for the rapidly increasing population of the country. The change in the age composition of the population is also likely to raise food requirements. As medical aid is becoming more widely available, fewer people will die young and more will grow to manhood than before. This would increase the proportion of adults in the coming years and lead to a

heavier demand for food for any given size of total population. The partition of the country in 1947 also affected the agricultural economy of the nation. While the Indian Union received 82% of the total population of undivided India, it got only 75% of the total cereal production, 65% of the wheat production, and 68% of the rice production (57). Of the total irrigated area 31% went to Pakistan, and 69% remained with the Indian Union (57). A change in the food habits of certain sections of the population, especially the labor class, is also important in a country with a limited supply of food grains. While previously they depended to a large extent on coarse grains like sorghum, maize, and other millets, they are now taking to wheat and rice to an increasing extent. It is worthwhile to mention here that, when the total requirements of an increasing population threaten to approximate or outrun the productive capacity of the land, the excess population must either be removed by famine, death, and migration, or the entire population must adjust itself to a fall in the standard of living which is already low when compared with western standards.

The agricultural sector plays a very important role in India's export trade. The income from the export cess levied on certain agricultural commodities under the Agricultural Produce Cess Act of 1940 in 1953-54 alone was estimated at 4.9 million rupees[1] (71). The export of agricultural commodities like tea, coffee, tobacco, lac, jute, pepper, etc. is of great help to the country in earning foreign exchange. Agriculture is also the basis of various industries such as textile, sugar, and others.

The expansion in agricultural production thus becomes inevitable if India is to meet the food requirements of its increasing population, provide for a higher standard of living of the people, earn the foreign exchange for the general economic development of the country, and supply raw materials for its important expanding industries. The inter-relationship of the agricultural sector with the entire economy of the nation and the very important role which this sector does and must continue to play in the development of India will be still clearer from the discussion to follow.

PHYSICAL FACTORS AND THEIR IMPORTANCE

The physical features of India present a variety probably unrivalled by any other area of similar size on the globe. The country lies partly in the tropics and partly in the subtropics. Physiographically, India may be divided into four parts: the Southern Peninsular region, the Himalayas and associated mountains, the Indo-Gangetic alluvial plains, and the Thar Desert. Except for a fairly broad strip along the east coast and a comparatively narrower one along the west coast, most of the surface of the peninsula is composed of hills and plateaus. The coastal plains are the most productive parts of the peninsula. The Himalayas and associated ranges of northern India are folded mountains of the Tertiary Age. The Indo-Gangetic plains lie between the Himalayas and peninsular India and represent a sag or depression in the earth's crust which has been filled up with alluvium brought down by rivers. These plains constitute one of the most fertile tracts in the world. The Thar Desert is an arid region in the northwest, occupying a large part of Rajasthan.

The climate of India, the geographical area of which has been recently estimated at 806 million acres[2] (22), shows a considerable range. Conditions in the north differ greatly from those in the south, the

[1] At the current rate of exchange $1.00 is equivalent to 4.75 rupees.

[2] 2.47 acres are equivalent to one hectare.

coasts differ from the interior, and the west coast is different from the east coast. The rainfall, which more than any other meteorological condition exercises the greatest influence on vegetation, is extremely variable. A unique feature of the rainfall in India is its unequal distribution during the year and its fluctuation from year to year in respect to quantity, incidence, and duration. As the Indian farmer primarily depends on rain for the supply of water to his land, this factor is of prime importance in Indian agriculture. While the average annual rainfall in India is about 50 inches, there are considerable variations in the amount received in different regions. With an annual average of about 460 inches, Cheerapunji in Assam receives the highest rainfall in the world. Other places of high rainfall, with an average of 300 to 400 inches a year, lie in the Western Ghats. At the other extreme are regions like parts of Rajasthan which hardly receive even three to five inches of rain annually. During the southwest monsoon the air is supersaturated with moisture in the coastal areas and in the hills, while during the dry weather (April-May) the same places may show a very low humidity. The hill stations in the Himalayas may be shrouded in clouds for days together in September with humidities of close to 100%, while in November the same area may be overrun with air of practically zero humidity. No less striking is the contrast exhibited by temperature conditions. Arctic conditions prevail throughout the year in some of the Himalayan and Trans-Himalayan ranges. At the other extreme, there are places in the northern plains where the temperature in May and June may go so high (45.5° C. to 47.7° C.) as to make life uncomfortable.

The agriculture of a country is dependent to a large extent on the nature and property of its soils. In general the soils of India have been classified into four major types (53) the Indo-Gangetic alluvium, the black cotton soils, red soils, and the lateritic soils. The Indo-Gangetic alluvium is by far the largest and most important of the soil groups of India. This covering an area of about 300,000 square miles, is agriculturally the most productive soil of the country. As the name indicates, the black cotton soils of India are especially suitable for the cultivation of cotton. They are comparable with the 'chernozems' of the U.S.S.R. and the 'prairies' of the cotton-growing regions of the U.S.A. The red soils grade from the poor, thin, gravelly and light-colored varieties of the uplands to the much more fertile, deep, and dark varieties of the plains and valleys. They are generally poor in nitrogen, phosphorus, and humus. The laterite is a formation peculiar to India and some other tropical countries with an intermittently moist climate. It is a compact to vesicular rock composed essentially of a mixture of hydrated oxides of aluminum and iron with small amounts of manganese oxide, titanium, etc. All lateritic soils are poor in lime and magnesia and deficient in nitrogen.

In addition to the four major soil groups described above, there are four other groups which are of minor importance in agriculture. These include forest and hill soils, desert and semi-desert, saline and alkaline, and peaty and marshy soils. Nearly 14% of the total area of the country is under forests. The formation of these soils is mainly governed by the characteristic deposition of the organic matter derived from the forest growth. A large part of the arid region belonging to Rajasthan and south Punjab is affected by desert conditions. This part is covered by a mantle of blown sand and is agriculturally unproductive because of its highly sandy composition and the absence of surface water. The Rajasthan desert proper occupies an area of about 40,000 square miles. The distribution of saline and alkaline soils is quite extensive throughout India. Peaty soils originate in humid regions as a result of the accumu-

lation of large amounts of organic matter. They may contain in addition considerable amounts of soluble salts. The depressions formed by dried river basins and lakes in alluvial and coastal areas sometimes give rise to peculiar water-logged and anaerobic conditions of the soil. These marshy soils are generally blue due to the presence of ferrous iron and also contain varying amounts of organic matter.

From the preceding paragraphs it is clear that the topography, climatic conditions, and soils of India are extremely heterogeneous. The variations in these factors result in the varied types of agriculture seen in India.

THE STRUCTURE AND PROBLEMS OF INDIAN AGRICULTURE

Although agriculture occupies a significant place in the economy of the country, its efficiency still leaves much to be desired. At this point, it is worthwhile to point out some of the factors which have contributed to this inefficiency. The efforts of the Government to cope with them are discussed in the concluding part of the article.

Although the land has been under cultivation for centuries, it is only during recent times that the pressure of population has made intensive agriculture a necessity. As a result the soil fertility, which was originally high, has been lowered to a point where good yields are uncommon and the average yields are very low in comparison with those of countries not subjected to a long-continued and intensive agriculture. Indian soils are generally deficient in nitrogen and phosphates. One of the commonly used organic manures in Indian agriculture is farmyard manure which is a by-product in farming by bullocks. Although, on the basis of the 1951 livestock census, the total production of fresh dung is estimated at 800 million tons, all of this does not go back to the land. In fact, as much as 50% of it is burnt away as fuel. Bonemeal is a rich form of phosphatic manure which also contains both organic matter and nitrogen. The average annual collection of bones in India amounts to about 150,000 tons which is really only one fourth of the estimated quantity available, judging from the number of cattle that die in a year. About 25% of the available supply of bones is converted into bonemeal, and the remaining 75% is exported as grist for which there is a considerable demand in foreign countries for the manufacture of glue and gelatine. The phosphatic deficiency is sought to be met by importing rock phosphate and converting it into superphosphates. Grist fetches high prices, and there is certainly some saving to the country in its export and its substitution by superphosphates as a source of phosphatic fertilizers. On the other hand, while bonemeal also contains organic matter and nitrogen, these are not present in superphosphates. From what has been said about the loss of farmyard manure in the country and the export of bonemeal to other countries, it is clear that only a small proportion of the potential organic manurial resources of the country is being utilized as against the actual requirements of the area under cultivation. The practice of green manuring is an important feature of Indian agriculture and makes up the deficiency to some extent. The most commonly used green manuring plants are (34): sunn hemp *(Crotalaria juncea)*, dhaincha *(Sesbania aculeata)*, guar *(Cyamopsis tetragonoloba)*, berseem *(Trifolium alexandrinum)* and cowpea *(Vigna sinensis)*. Some of the crops with which green manuring has been adopted are transplanted paddy, sugarcane, and irrigated wheat. From the point of view of cultivators having very small holdings, however, the economics of green manuring will largely depend upon the possibility of producing green manure crops without disturbance to the main crops which support the finances of the cultivator.

The large land resources of India cannot be put to productive use without a simultaneous development and use of the country's water resources. The gross irrigated area in 1953-1954 was 61,334 thousand acres representing about 20% of the gross cultivated area (22), the remaining 80% being dependent on rainfall which is seldom adequate and timely. An annual failure of crops in one or the other region is, therefore, a common feature of Indian agriculture, and an integrated development of the land and water resources of the country is of fundamental importance to the country's economy.

Dry farming, or the growing of crops in regions of low, uncertain and variable rainfall, is considered as one of the major problems of agriculture. Although no detailed survey has been carried out of the dry farming areas in India, it may be fairly safe to estimate that these comprise one third of the total arable land (6). Dry farming tracts have been described by American workers as those areas which receive less than 20 inches of annual rainfall. Under tropical conditions this limit has to be raised to compensate for the loss of moisture by evaporation. For example, in the dry farming regions of the U.S.A., Canada, or Australia, with mean annual temperatures of 4.4° C. to 15.5° C., it is possible to grow a fairly successful crop with even ten to fifteen inches of annual rainfall. In India, where the mean annual temperature in these areas is about 26.6° C., the equivalent rainfall will have to be from 25 to 42 inches. Although the principles of dry farming are well known, it is necessary to work out the details to suit different areas. Some work has already been done on this problem as well as on soil conservation, and the area under improved methods of dry farming is on the increase.

Small and uneconomic holdings are at the root of many difficulties in the way of agricultural development in India. Further, these holdings are generally fragmented into a number of plots scattered over different parts of the village. It may be noted that the number of holdings with an average area of two acres is as high as 23,400 for a plantation crop like rubber (1). Anything below four acres per tapper cannot be considered an economic holding. In a farm of substantial size it is possible to eliminate several wasteful operations and to insure better use of the land. Economies which cannot be availed by small holdings are available to large ones. Although there are numerous difficulties such as the peasant's indebtedness, sentimental attachment to particular plots, and want of adequate area of the same kind of land for exchange, the Government is taking measures for increasing the size of the uneconomic holdings and their consolidation into compact blocks.

Double cropping as a means to increase agricultural production offers a wide scope in India (45). It is possible to adopt this practice in regions of medium to high soil fertility and an assured water supply in both seasons. However, the subsidiary crops following the main ones should be such that they would maintain the soil in condition. Pulses, in general, serve as good catch crops. In addition, they also act as cover crops. Rice, wheat, and millets occupy only one season. The second season in millets is occasionally devoted to a crop sown together with the millets which may be harvested with them or after the gap of a few months. In rice or wheat tracts, a very high proportion of the area is left fallow. It is in these tracts that the possibilities of double cropping are appreciable. Some of the important double cropping systems followed are: 1. rice—rice; 2. rice—pulses; 3. groundnut—wheat; 4. wheat—maize.

Another effective method of securing increased production in the country is through multiplication and distribution of improved seed. It has been noted that the improved seed of commercial crops like

cotton, sugarcane, tobacco, etc. spreads much faster than that of the food crops. About 70% of the total acreage under cotton in India is grown with improved varieties. Assuming the additional returns gained by the cultivation of improved varieties in cotton at ten rupees per acre on an average, the total additional income earned during 1955-56[3] is estimated to be about 136 million rupees (48). The scope for raising the average yields through the use of improved seed in other crops, particularly food plants, is considerable. While the private sector has not shown any interest in establishing seed farms, the Government has recently undertaken seed supply schemes in order that the cultivators may get pure improved seed at reasonable rates.

ORGANIZATION AND DEVELOPMENT OF AGRICULTURAL RESEARCH

Although agriculture has such an important role in India's economy, no definite governmental policy for its improvement existed before 1903. In that year, the Government laid the foundation of organized research by the establishment of an agricultural research station and an experimental farm at Pusa. This was done with the help of a donation of £30,000 given by Henry Phipps of Chicago (71). In 1928 a Royal Commission was appointed to report on conditions of agriculture and rural economy in this country. The Commission proposed the establishment of a Central Council of Agricultural Research with the primary function of promoting, guiding, and coordinating agricultural research throughout India. In pursuance of this recommendation, the Indian (at that time called 'Imperial') Council of Agricultural Research was set up as a statutory body in 1929. The Council does not have any research institute of its own but finances approved research projects carried out in government institutes, universities, and recognized private institutions.

Apart from the I.C.A.R. there are a number of commodity committees which confine themselves to research on particular crops. These are semi-autonomous bodies financed by a cess levied on the commodity concerned or by a grant from the Central Government. The earliest commodity committee to be organized is the Indian Central Cotton Committee which was established in 1921. This committee has given a great stimulus to research on cotton. Work under the guidance of the committee has resulted in evolving a number of improved types of cotton. Realizing the benefits of commodity approach to research, many other commodity committees were organized. Thus, the Indian Lac Cess Committee was established in 1931; the Indian Central Jute Committee in 1936; the Indian Central Sugarcane Committee in 1941; the Indian Central Tobacco Committee and the Indian Central Coconut Committee in 1945; the Indian Central Oilseeds Committee in 1947; and the Indian Central Arecanut Committee in 1949. A number of research institutes for fundamental as well as applied work are under the direct control of the Central Government. One of these is the Indian Agricultural Research Institute established in 1905 at Pusa but shifted from there to New Delhi after the disastrous earthquake of 1934. Some of the other institutes included under this category are the Sugarcane Breeding Institute, Coimbatore; the Central Rice Research Institute, Cuttack; and the Central Potato Research Institute, Simla. In addition to the Central Government organizations, each state in India has a well organized department of agriculture. The Director of Agriculture, who is head of this department, is responsible

[3] The financial year of the Government begins in April and ends in March next. Thus, 1955-56 means the financial year beginning with April, 1955, and ending with March, 1956. This explanation applies to all other similar cases in the course of the paper.

for all agricultural activities in the state. The functions of the state agricultural departments are: organization of research projects chiefly of importance to the state, imparting agricultural education, demonstration, and supply of improved seed, manure, implements, etc. As plantation crops occupy a very important position in India's foreign trade, research on them is being organized by a separate board for each. Thus, the Coffee Board, the Tea Board, and the Rubber Board are playing an important part in safeguarding the interests of the respective industries.

Agricultural research in India is financed by grants made by the Central Government and the state governments and by the proceeds from cess or export duty levied on some of the agricultural commodities like tea, coffee, lac, rubber, jute, and cotton. The annual provision for agricultural research in India is about 80 million rupees (71). The corresponding figure for the U.S.A. is nearly 550 million rupees (71).

THE FOOD-PRODUCING CROPS

Although about 78% of the total gross cropped area of 356 million acres in India (22) is under food crops, the major problem confronting the country is to increase its food production to the point that it could keep pace with the growing demands of the expanding population. While the population in 1951 had increased by nearly 82 million over what it was in 1931, there was no appreciable change in the production of food grains during that period. The increase in the annual demand for food grains on account of this rise in population has been estimated at about 450,000 tons. To augment internal supplies, the newly-born Republic of India had no other alternative but to import large quantities of food grains. Rice and wheat constituted a major part of these imports. This was a significant drain on India's foreign exchange balances. It is thus of prime importance that the nation's food production should attain a level of self-sufficiency as rapidly as possible. The requirement of cereals alone has been laid down by the Nutrition Advisory Committee at 14 ounces per day. To raise consumption to this level, the additional quantity required is estimated at 7.8 million tons annually.

The Government and Food Production

The food problem has been engaging the attention of the Government for a long time. In 1942 a conference was called to discuss ways and means for increasing the food production and its recommendations formed the basis of what has come to be known as the "Grow More Food" (GMF) campaign. The main lines of action between 1943 and 1947 were: (a) a switch over from cash crops, mainly short staple cotton, to food crops; (b) intensive cultivation; and (c) extension of the cultivated area by bringing under the plough current fallows and cultivable waste land. In pursuance of a decision taken in 1946 the GMF movement was placed on a planned basis and the target of additional production was fixed at four million tons for the next five years. However, the expected objective of self-sufficiency still remained unachieved. In 1951-52 the Planning Commission of the Government prepared its First Five Year Plan including schemes for increased food production. As indicated by Tables I and III there has been an increase in production of almost all the major food crops. Food grain production went up by 20% during the period 1951-52 to 1955-56. In 1956-57 the production of food grains was 68.6 million tons as compared to 65.2 million tons in 1955-56. Production of rice went up from 26.8 million tons in 1955-56 to 28.1 million tons in 1956-57. Similarly, wheat increased from 8.6 million tons in 1955-56 to 9.1 million tons in 1956-57. Gram showed an increase of about 11% from

5.3 million tons in 1955-56 to 5.9 million tons in 1956-57. However, the country is still far from reaching the stage of self-sufficiency with regard to its food requirements.

In its effort to increase the food supply, the Government has used a number of methods simultaneously. It appears that the most significant programs of development contributing to the increase in food production have been minor irrigation works, increased use of fertilizers, land reclamation and development, and the extension of the area under cultivation. Crop competitions were started in 1949-50 to promote a spirit of healthy rivalry among agriculturists and encourage them to raise their yields.

Cereals

Cereals constitute the most important group in the food plants of India. The production of the major cereals grown in the country is indicated in Table I. These along with others will now be discussed.

Rice (*Oryza sativa* L.). Rice is predominantly a crop of Asia, 95% of the world's area being concentrated in southeastern Asia extending from west Pakistan to Japan. India has the largest area—79 million acres—in the world under rice cultivation, and production is about 28 million tons per year. Although it cannot be said with certainty, India and Indo-China might well have been the centers of origin of *Oryza sativa* (47). The varietal diversity is nowhere so great as in India, and it is here that the wild form, *Oryza sativa* var. *fatua*, occurs in abundance. It is believed that the cultivation of rice in India dates back to ancient periods even earlier than 3000 B.C. (42). Carbonized paddy grains were found in the excavations at Hastinapura in northeastern India at a site which has been dated as circa 1000-750 B.C. (15). These are the oldest specimens of paddy yet known in the world. The crop is cultivated in almost all the states of India, extending from the delta regions of the south to the higher altitudes of 3,000 to 5,000 feet above sea level in the Kashmir Valley in the north. Its cultivation is, however, mostly concentrated in the valley of the Ganga and its delta and the low-lying coastal areas in southern and northeastern India. The crop is usually classified into two categories: the 'wet' or lowland rice and 'dry' or upland rice. The 'wet' rice occupies low areas where water is plentiful throughout the rice season. The varieties grown are generally of long duration (150 to 180 days). The 'dry' rice is always rain-fed, and varieties of shorter duration, 90 to 125 days, are usually grown. Lowland rice, due to the copious and more assured water supply, outyields upland rice. It is also classified as 'aus' (autumn), 'aman' (winter), and 'boro' (summer), according to the season when it is harvested

TABLE I
PRODUCTION OF MOST IMPORTANT CEREAL CROPS IN INDIA, IN THOUSAND TONS

Commodity	1950-51	1951-52	1952-53	1953-54	1954-55	1955-56	1956-57
Rice	20,251	20,964	22,537	27,769	24,531	26,846	28,142
Wheat	6,360	6,085	7,382	7,890	8,778	8,569	9,068
Sorghum	5,408	5,981	7,243	7,954	9,093	6,062	7,427
Maize	1,702	2,043	2,825	2,991	2,939	2,554	3,020
Pearl Millet	2,554	2,309	3,142	4,475	3,421	3,379	2,926
Barley	2,340	2,330	2,882	2,905	2,870	2,749	2,744
Finger Millet	1,407	1,291	1,316	1,846	1,646	1,820	1,914
Small Millets	1,722	1,885	1,895	2,438	2,456	1,937	2,010
TOTAL	41,744	42,888	49,222	58,268	55,734	54,456	57,251

Source—Bulletin on Food Statistics. Ministry of Food and Agriculture, Government of India, 1958.

(59). The 'aman' rice, sown in June and July and harvested about November and December, is by far the most important. The 'aus' crop sown in May is usually harvested in September. The 'boro' rice, which is the least important of the three, is sown in January and February and harvested during May and June. Though over large areas one crop is taken yearly, two or occasionally even three crops a year are grown in localities where the winter temperature is not low and irrigation facilities are available The present average yield of about 800 lbs. of clean rice per acre is very low; but it is higher (1,200 to 1,500 lbs.) in areas with irrigation facilities and where the crop is manured. In recent crop competitions yields of 4,000 to 6,000 lbs. of rice per acre have been recorded, showing thereby the potentiality of some of the areas.

Although the production of rice went up from 26.8 million tons in 1955-56 to 28.1 million tons in 1956-57, India's annual requirement of rice still exceeds her production, and the deficit has to be met by imports. The area, production, and imports of rice from 1951-52 to 1955-56 are shown in Table II. To enable a supply of food grains at reasonable prices to the

TABLE II
ACREAGE, PRODUCTION, AND IMPORTS OF RICE

Year	Area (Thousand Acres)	Production (Thousand Tons)	Imports (Thousand Tons)
1951-52	75,205	20,964	659
1952-53	74,030	22,537	632
1953-54	76,960	27,769	197
1954-55	75,726	24,531	795
1955-56	76,864	26,846	59

consumers and to build up reserve stocks, the Government has entered into an agreement with Burma for the import of two million tons of rice over a period of five years commencing from 1956 and with the U.S.A. for the import of 190,000 tons of rice over a period of three years again commencing from 1956 (25). In spite of the fact that India is a deficit country, small exports are made to the U.K., Aden, Kenya, and a few other places; but these chiefly comprise the fine and scented varieties of rice. The quantities exported in 1954-55 and 1955-56 were 28,238 tons and 110,744 tons, respectively (21).

During the last few years considerable interest has been aroused in India in the so-called Japanese method of rice cultivation. This merely combines improved cultural practices with judicious manuring and plant protection measures. The increased acre-yields obtained by this method have naturally led to its popularity. Up to 1956, 1.6 million acres of rice area in India were brought within its scope. The results of breeding for high yield have also been very satisfactory, and many improved varieties have been evolved which give an enhanced yield of 10 to 15%. Some of the new varieties are highly resistant to the blast disease *(Piricularia oryzae)* and also possess desirable agronomic characters. Two such types, *viz.* CO.25 and CO.26, are notable examples. It has been realized that the newer intensive methods of cultivation and manuring demand varieties which are capable of giving still higher field responses. With this aim in view there has been started an intensive hybridization program between the *japonica* and *indica* varieties of rice. The *japonica* varieties are high yielders giving a better response to intensive manuring and possess short non-lodging straw, while the *indica* varieties have a better tillering capacity and are resistant to diseases and adverse climatic conditions.

Wheat (*Triticum* spp.). Wheat is the second staple food crop of India and occupies about 29 million acres of land. It is consumed mainly by the people in the north. The wheat grains discovered as a result of the Indus Valley excavations at Mohenjo-daro indicate that northwestern India was one of the ancestral

lands of this cereal (40). The carbonized grains resemble those of *Triticum sphaerococcum* Percival, an endemic species, which is still found in a few places in India. The wheat-growing area in India can be broadly divided into three main divisions, namely the Gangetic alluvium, the Indus Valley, and the black soil tract of peninsular India. The first two areas, in northern India, have irrigation facilities while most of the area in peninsular India is unirrigated. A special feature of Indian wheat is the relatively short season in which it completes its life cycle. While the crop stands in the field for nearly nine to ten months in some western countries, in India it is ready for harvest in four to six months after sowing. Only in the hills of north India is the growing season for wheat about nine months, but the area under the crop in this region is very small.

Of the 18 recognized species under the genus *Triticum*, five are cultivated in India (35). Of these, *Triticum aestivum* L. (*Triticum vulgare* Vill.), commonly known as the bread wheat, occupies the largest area and is mainly grown in the northern regions. This is specially suitable for making "chapatis".[4] Next in importance is the macaroni wheat, *T. durum* Desf., which is the predominant species in central and western India. The area under *T. dicoccum* Schrank. grown in south India and parts of Bombay is rather small. *T. turgidum* L., the rivet wheat, and *T. sphaerococcum* Percival, the dwarf wheat, are even less important.

The average yield of 630 lbs. per acre in India is rather low when compared to that of the other wheat-growing countries of the world. Although the production of wheat increased from 8.6 million tons in 1955-56 to 9.1 million tons in 1956-57, the country is still not self-sufficient with regard to its requirements. The deficit is being made good by heavy imports from other countries like Australia and the U.S.A. The Government of India has recently entered into an agreement with the U.S.A. for the import of 3.1 million tons of wheat over a period of three years commencing from 1956 (25).

Wheat was the first crop to attract the attention of Indian breeders. The main object was to evolve high-yielding varieties with good grain quality. This resulted in the evolution of varieties like N.P.4, N.P.12, N.P.52, and N.P.165.[5] A notable achievement of the last few years has been the evolution of a new series of improved wheats. Their special characters include adaptability to certain regions, high yield, good grain quality, tolerance to rusts, and resistance to loose smut. N.P.710 was found to be the most widely adapted among them. In most wheat-growing countries only one or two rusts are of importance, but in India all the three rusts, namely, the black, brown, and yellow, caused by *Puccinia graminis tritici*, *Puccinia triticina*, and *Puccinia glumarum*, are found to do considerable damage in the major wheat-growing areas in the north. In peninsular India only the black rust is of importance. The average annual loss through rust to the wheat crop in India is estimated at about 60 million rupees, and in some years the losses are much greater. Breeding of rust-resistant varieties has been engaging the attention of Indian botanists for the last several years. Some strains possessing a high degree of resistance to each rust have been developed. Crosses were also made with a view to developing varieties which may combine resistance to all three rusts. N.P.809, which has done very well in the hills, possesses an appreciable degree of resistance to all the three rusts in the adult stage, besides being agronomically superior.

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[4] In India wheat flour is largely used in making flat unleavened cakes known as "chapatis".

[5] The (letters) 'N.P.' standing for 'New Pusa' are prefixed to the numbers of improved strains of crops bred at the Indian Agricultural Research Institute, New Delhi.

Maize (*Zea mays* L.). Maize is said to have been introduced in this country from tropical America about the beginning of the seventeenth century. The area under this crop measures 9.6 million acres with an annual total production of three million tons. Maize is mainly grown as a "kharif"[6] crop. Although it is grown throughout India, the chief concentration is in the northeastern parts. The crop is of special importance in the hilly and submontane regions where it forms the staple food of the people. It is utilized mostly as flour for "chapatis", green cobs for roasting, and dried grains for popping or parching in hot sand. Only in the northern parts is it also grown for fodder purposes. The flint type forms the bulk of the maize crop in the country. The average yield of about 600 lbs. per acre is quite low. As the production of hybrid corn seed involves a long-range process, it was thought advisable to import ready made seed from the U.S.A., Australia, and Canada with a view to finding out if any of them would suit Indian conditions. Some of these, such as U.S.13, Dixie II, and N.C.27, have given better yields than the local types. Steps have now been taken for the large-scale production of hybrid maize seed in the country itself.

Barley (*Hordeum vulgare* L.). Barley, an important "rabi" cereal of northern India, is grown pure or as a mixed crop. It is specially important in the hills. The area under barley in India is 8.4 million acres and the annual production 2.7 million tons. Both the six-rowed and the two-rowed types are under cultivation. The grain is chiefly utilized in the form of flour for making "chapatis". Considerable quantities are also used for malting and brewing. Although the average yield of the crop is about 900 lbs. per acre, it is much higher in regions with facilities for irrigation. Some of the improved strains such as N.P.13, N.P.21, C.155, and C.251 are grown extensively.

Oat (*Avena sterilis* L. var. *culta*). In India oats are of much less importance than the other cereals mentioned above and are grown mainly for fodder. The Indian oat belongs to the species *Avena sterilis* var. *culta*, also known as *Avena byzantina* Koch., which is different from *A. sativa* L. commonly cultivated in the temperate climate of northern Europe (14). The species cultivated in India is identical with that in the Mediterranean countries. The plant is generally grown as a minor "rabi" crop, pure or mixed, on a wide range of soils. Two improved types, N.P.1 and N.P.2, have been selected from the mixed country crop. These are superior in yielding ability and resistance to drought but possess grains of low quality. As a result of hybridization between *Avena sativa* and *A. sterilis*, a number of promising types have been evolved which combine the good grain quality and straw-ability of the former with the early maturity and drought resistance of the latter (73).

Millets. In India millets are considered to have been cultivated and used as bread grains from prehistoric times. Their importance as an article of human food can be realized from the fact that about 80 million acres in the country fall under this group of plants. The annual production is estimated to be about 12 million tons (23). Millets are generally grown as mixed crops in regions of low rainfall, the other crop grown with them being usually one of the pulses. Most of the millets grown in the country are of short duration, taking three to four months from sowing to harvesting. Some of the commonly grown millets in India are sorghum (*Sorghum vulgare* Pers.), pearl millet [*Pennisetum typhoides* (Burm.) Stapf & Hubbard], finger millet [*Eleu-*

[6] "Kharif" crops are generally sown in May and June and harvested in August and September, whereas "rabi" crops are sown in September and October and harvested in March and April.

sine coracana (L.) Gaertn.], Italian millet [*Setaria italica* (L.) Beauv.], kutki (*Panicum miliare* Lam.) and kodo (*Paspalum scrobiculatum* L.). Of these, sorghum, pearl millet, and finger millet are more widely cultivated and will be dealt with individually.

Sorghum (*Sorghum vulgare* Pers.). India is one of the leading countries in the world for the production of sorghum. The area under this millet is 42.6 million acres, and the production of the grain is estimated at about 7.4 million tons. The grain is eaten by breaking it and cooking it in the same way as rice or by grinding it into flour and preparing unleavened bread from it. The crop is also used for fodder purposes especially in the north. Although it is grown in central and northern India, its main area of cultivation lies in the south. Though numerous foreign varieties have been obtained from Africa, the U.S.A., and China, none of these has outyielded the local improved types.

Fig. 1. A field of sorghum, var. Co. 1 (Photo by Mr M. A. Sankara Iyer, Agricultural College and Research Institute, Coimbatore).

Pearl Millet [*Pennisetum typhoides* (Burm) Stapf & Hubbard]. This is the second important millet of India. The area under the crop is 28.2 million acres, and the annual production of the grain is about three million tons. The crop is important both to the people of the north and the south. Its duration varies from about three to five months. The early varieties are generally preferred. Pearl millet differs from other millets in being protogynous. In recent years production of hybrid seed from selected parents has been in progress in south India. Two hybrid combinations have been found to excel local types, and seeds are being produced on a large scale for distribution to farmers.

Finger Millet [*Eleusine coracana* (L.) Gaertn.]. This ranks third in importance among the millets in India. The total area under the crop is 5.9 million acres and the estimated production is nearly 1.9 million tons. About 75% of the area under the crop lies in south India (73). It is also grown, to a limited extent, in the hilly tracts of northern India.

Legumes

Pulses. The pulses form an important item in India where the majority of the population consists of vegetarians. Being legumes they figure prominently in crop rotations and in the mixed cropping commonly practiced in Indian agriculture. Pulses are also important from the point of view of animal nutrition, to which they contribute by their seeds, hulls, and the green parts. About one seventh of the cultivated area in the country is under pulses (31). Of this about 37% is occupied by gram and 13% by the pigeon pea.

These two are, therefore, dealt with individually. In addition to gram and pigeon pea, some of the other common Indian pulses are: black gram (*Phaseolus mungo* L.), green gram (*Phaseolus aureus* Roxb.), lentil (*Lens culinaris* Medik.), peas (*Pisum* spp.), grass pea (*Lathyrus sativus* L.), and dew gram (*Phaseolus aconitifolius* Jacq.). The area and the production of some of these are shown in Table III.

Gram (*Cicer arietinum* L.). Also known as the Bengal gram or the chick pea, this is the most important pulse in India, ranking fourth in production and fifth in acreage among the food grain crops. It is consumed in several ways. "Dhal" which is prepared by splitting the whole grain into two and removing the husks (morphologically, the testa) is one form in which gram is commonly used in India. "Dhal" flour, known as "baisan", is used in the preparation of unleavened bread and sweets. The whole grain is eaten raw, roasted, parched, or boiled. Gram is also used for feeding livestock. The main producing areas are the upper basins of the Ganga and the adjacent tracts of central India. There are several varieties differing in color and size of seed. These are classified into two broad groups, brown and white. The brown or "desi" type is the most widely grown and comprises a great many shades, ranging from yellow to dark reddish brown or even black. The white or "kabuli" gram is characterized by larger seeds but gives a comparatively poor yield.

Pigeon Pea [*Cajanus cajan* (L.) Millsp.]. Grown mostly as a "kharif" crop and used in the form of "dhal", this is the second important pulse crop of India. The pericarp and husk, which are separated in threshing, constitute a valuable cattle feed. There are two main varieties: arhar (*Cajanus cajan* var. *bicolor* DC.) and tur (*Cajanus cajan* var. *flavus* DC.). Under the former come the late-maturing, large, bushy plants, bearing purple-streaked, yellow flowers and dark-colored pods, each having four or five seeds. Tur, on the other hand, comprises early-maturing and smaller plants having yellow flowers and plain pods, each containing two or three seeds. Tur is commonly cultivated in the peninsular region and arhar in northeastern India. Some of the improved types evolved in India include N.P.15, N.P.16, N.P.64, N.P.80, and type 17 of U.P. Of these N.P.80 is highly resistant to the wilt disease caused by *Fusarium*.

Subsidiary Foods

The principal subsidiary food crops of India are potato, tapioca, and sweet potato. With their high yields per acre, they have a special importance in a country deficient in food grains.

TABLE III
PRODUCTION AND AREA OF PULSES IN INDIA

	1951-52	1952-53	1953-54	1954-55	1955-56	1956-57
			Production in Thousand Tons			
Gram	3,334	4,142	4,756	5,393	5,331	5,930
Pigeon pea	1,801	1,675	1,834	1,688	1,830	2,047
Other pulses	3,152	3,227	3,860	3,789	3,670	3,458
Total	8,287	9,044	10,450	10,870	10,831	11,435
			Area in Thousand Acres			
Gram	17,205	18,251	19,996	22,953	24,157	23,990
Pigeon pea	6,229	6,198	6,143	6,138	5,637	5,696
Other pulses	26,748	26,833	28,096	27,634	27,270	27,609
Total	50,182	51,282	54,235	56,725	57,064	57,295

Potato (*Solanum tuberosum* L.). The potato was introduced into India in the seventeenth century. The tubers are consumed as a vegetable rather than as a staple food because of their high price during a large part of the year. Lowering the cost depends very largely on providing facilities for storage, dehydration, and transport at a much cheaper rate than at present. The per capita annual consumption of potatoes is estimated at nine lbs., while in some of the western countries the figure is as high as 440 lbs. (44). With an area of 702,000 acres, the annual production is estimated at 1,674,000 tons. About 90% of the crop is grown in the north Indian plains in winter and the rest in the hills in summer. In the cooler elevations of the peninsula, particularly in the Nilgiris, the crop is cultivated all the year round. In the plains, especially in areas near large towns where intensive cultivation is practiced, two successive crops are sometimes raised on the same land. The commonly grown varieties are 'Phulwa,' 'Darjeeling Red Round,' 'Up-to-date,' and 'Gola'. Several newly evolved high-yielding hybrids, such as 208, 209, 2236, and 0. No. 45, have been found to be very suitable for cultivation in north Indian plains.

Tapioca (*Manihot esculenta* Crantz.). Also known as cassava, this plant is a native of tropical South America. According to MacMillan it was introduced by the Portuguese in the seventeenth century while Burkill states that it was introduced from South America into India in 1840 (2). Tapioca forms the chief item of food for a considerable proportion of the population on the west coast of south India. It is commonly used as fresh tubers, boiled and prepared in the same way as potatoes. While attempts have been made to extend its cultivation into new areas, Kerala with more than half a million acres under the crop remains the chief tapioca-producing state of the country. The crop thrives best under a warm, humid climate. The average yield per acre in India is about five to six tons of raw tubers. Two good hybrids produced in the country are H.96 and H.105. Two introductions from Malaya, M4 and M6, have also proved to be high yielders.

Fig. 2. (Left) Mature tapioca plants (Photo by Mr. H. B. Singh, Indian Agricultural Research Institute, New Delhi).

(Right) The basal portion of a tapioca plant showing mature roots.

Sweet Potato [*Ipomoea batatas* (L.) Poir.]. This plant is grown all over India and gives good yields even in comparatively poorer soils. It requires a fairly high temperature to grow satisfactorily and is usually planted in early July. Where facilities for irrigation are available, early planting in May and June gives better yields. People in various parts of India seem to have a traditional preference for one or the other color of the skin of the tuber. In the Punjab (northern India) white sweet potato is hardly grown, while in Mysore (southern India) it is the white varieties which are preferred. In other parts of India, both red and white varieties are popular. However, no particular desirable or undesirable attributes are known to be associated with the color. From over a hundred Indian and foreign varieties tried at the Indian Agricultural Research Institute, New Delhi, 'Pusa Suffaid' and 'Pusa Sunehri' have outdone all the rest in respect to yield, quality, and nutritive value. 'Pusa Suffaid' and 'Pusa Sunehri' are selections from the material obtained from China and the U.S.A., respectively (67).

Fig. 3. Tubers of sweet potato var. *Pusa Suffaid* (Photo by Mr. H. B. Singh, Indian Agricultural Research Institute, New Delhi).

Fruits and Vegetables

India grows a large variety of vegetables and fruits belonging to the tropical, sub-tropical, and temperate groups. However, their present availability is only 1.3 and 1.5 ounces per adult per day. On the other hand, a balanced diet requires ten ounces of vegetables and three ounces of fruits.

A good number of the vegetables and fruits grown in India are introductions from foreign countries. A list of some of the more commonly grown items is given in Table IV.

COMMERCIAL AND PLANTATION CROPS FOR LOCAL CONSUMPTION

Commercial crops which provide the raw material for industries account for 17% of the cropped area (19). Plantation crops and spices cover no more than 1.1% of the area. However, they not only occupy a position of great importance in the economy of the valley in the northeast and the strip of territory along the southwest coast of India but also play a vital role in India's foreign trade (19). Only such of the commercial and plantation crops which are consumed locally will be discussed here, and an account of the rest will follow under "The Export Crops".

Cotton (*Gossypium* spp.). The cultivation of cotton and its manufacture into textiles have been practiced in India since prehistoric times. The most ancient cotton fabrics known to the world are the fragments of a material discovered in the excavations at Mohenjo-daro which are believed to be about 5,000 years old (65). Cotton, as the raw material for the Indian textile industry, provides factory employment for about 0.7 million persons and also contributes to the Government a substantial revenue from export and excise duty. While the crop can be grown on a variety of soils and under

TABLE IV
VEGETABLES AND FRUITS COMMONLY GROWN IN INDIA

Common Name	Botanical Name	Family
	Vegetables	
Bitter gourd	*Momordica charantia* L.	Cucurbitaceae
Bottle gourd	*Lagenaria siceraria* Standl.	Cucurbitaceae
Brinjal	*Solanum melongena* L.	Solanaceae
Cabbage	*Brassica oleracea* L. var. *capitata* L.	Cruciferae
Carrot	*Daucus carota* L.	Umbelliferae
Cauliflower	*Brassica oleracea* L. var. *botrytis* L.	Cruciferae
Fenugreek	*Trigonella foenum-graecum* L.	Leguminosae
Sponge gourd	*Luffa cylindrica* (L.) M. Roem.	Cucurbitaceae
Pumpkin	*Cucurbita pepo* L.	Cucurbitaceae
Okra	*Abelmoschus esculentus* (L.) Moench.	Malvaceae
Onion	*Allium cepa* L.	Liliaceae
Parwal	*Trichosanthes dioica* Roxb.	Cucurbitaceae
Radish	*Raphanus sativus* L.	Cruciferae
Round gourd	*Citrullus vulgaris* Schrad. var. *fistulosus* Stocks	Cucurbitaceae
Tomato	*Lycopersicon esculentum* Mill.	Solanaceae
Turnip	*Brassica rapa* L.	Cruciferae
	Fruits	
Apple	*Malus sylvestris* Mill.	Rosaceae
Apricot	*Prunus armeniaca* L.	Rosaceae
Banana	*Musa paradisiaca* L.	Musaceae
Date	*Phoenix dactylifera* L.	Palmae
Fig	*Ficus carica* L.	Moraceae
Grape	*Vitis vinifera* L.	Vitaceae
Grape fruit	*Citrus paradisi* Macfad.	Rutaceae
Guava	*Psidium guajava* L.	Myrtaceae
Jambolan	*Syzygium cumini* (L.) Skeels	Myrtaceae
Litchi	*Litchi chinensis* Sonn.	Sapindaceae
Loquat	*Eriobotrya japonica* Lindl.	Rosaceae
Mandarin	*Citrus reticulata* Blanco.	Rutaceae
Mango	*Mangifera indica* L.	Anacardiaceae
Musk-melon	*Cucumis melo* L.	Cucurbitaceae
Papaya	*Carica papaya* L.	Caricaceae
Peach	*Prunus persica* Batsch.	Rosaceae
Pear	*Pyrus communis* L.	Rosaceae
Phalsa	*Grewia asiatica* L.	Tiliaceae
Pineapple	*Ananas comosus* Merr.	Bromeliaceae
Plum	*Prunus domestica* L.	Rosaceae
Pomegranate	*Punica granatum* L.	Punicaceae
Sapota	*Achras zapota* L.	Sapotaceae
Sweet orange	*Citrus sinensis* (L.) Osbeck	Rutaceae
Sweetsop	*Annona squamosa* L.	Annonaceae
Watermelon	*Citrullus vulgaris* Schrad.	Cucurbitaceae

different climatic conditions, nearly half of the total acreage is confined to a compact area in the peninsular region. The bulk of it is grown under rain-fed conditions. The indigenous species (*Gossypium arboreum* L. and *G. herbaceum* L.) thrive better in such areas, whereas the long stapled *G. hirsutum* L. which was introduced from the New World does well only under irrigation.

The cotton position deteriorated with the partition of the country under which Sind and West Punjab, growing cotton on about four million acres annually and producing nearly one million bales of good quality American cotton, went to Pakistan. In 1948-49 the internal production of cotton was only 1.8 million bales while the total requirement amounted to about 4.6 million bales. Owing to

measures taken by the Government, the cotton production in the country has shown a substantial increase (Table V).

TABLE V
PRODUCTION AND AREA OF COTTON IN INDIA

Year	Production (Million Bales of 392 lbs. each)	Area (in Million Acres)
1950-51	2.9	14.5
1951-52	3.1	16.2
1952-53	3.2	15.7
1953-54	3.9	17.2
1954-55	4.3	18.3
1955-56	4.0	19.9
1956-57	4.7	19.8

It is to be noted that the *per capita* consumption of cloth in India is only 16 yards per annum as compared with 60 yards in the U.S.A. and 40 yards in England (65).

A noteworthy feature of the increased production is that the expansion in output consists mainly of better quality cotton. Whereas only 25% of the acreage was under medium and long staple cotton at the time of partition, at present 75% of the cotton area is under such types. The favorable supply position of cotton in recent years naturally led to a decline in the quantity of cotton imported into India and to an increase in the quantity exported from the country. Thus, whereas the total quantity of cotton imported in 1950-51 was 0.81 million bales, the figure for 1954-55 was 0.62 million bales. Imports are mainly confined to such long staple cotton as cannot be produced in the country. At the same time the total export of cotton increased from 0.18 million bales in 1950-51 to 0.32 million bales in 1954-55 (16). The export is mostly confined to short staple types.

The average yield of cotton per acre during 1954-55 was 92 lbs. as against 78 lbs. in 1950-51. Even this compares unfavorably with the yields in other cotton-producing countries of the world. The figures for 1954-55 are: 439 lbs. in Egypt, 416 lbs. in Peru, 341 lbs. in the U.S.A., and 185 lbs. in Pakistan (16). Adaptations to local conditions and improvement in yield, ginning out-turn, staple length, and spinning quality have been the main objectives of cotton breeding in India. Some of the outstanding varieties evolved here are: *G. arboreum*—N.14, "Gaorani" 6, and "Virnar"; *G. herbaceum*—"Jayadhar" and "Vijalpa"; *G. hirsutum*—MCU 2 and H.14. The area under the improved varieties has increased from seven million acres in 1950-51 to about 11 million acres in 1954-55. Out of the total increase in acreage under improved varieties, long staple cotton alone accounted for more than three million acres.

Sugarcane (*Saccharum officinarum* L.). The sugar industry in India is the second largest industry in the country, next only in importance to cotton textiles. The value of sugar and gur (jaggery) produced in India is estimated at over 2,800 million rupees (68). The major portion of the production is utilized for the manufacture of gur. The yield in 1956-57 in terms of gur and sugar was 6.74 million tons and 2.02 million tons, respectively. During the last decade there has been a shift in demand from gur to crystal sugar, but even then more than 50% of the cane is converted into gur. This is because the price of gur, which is generally more popular with the rural population, is comparatively lower than that of the sugar. As will be seen from Table VI, there has been a steady increase in

TABLE VI
PRODUCTION AND AREA OF SUGARCANE IN INDIA

Year	Production of Cane (in Thousand Tons)	Area (in Thousand Acres)
1951-52	60,680	4,792
1952-53	52,600	4,376
1953-54	43,673	3,498
1954-55	56,923	3,994
1955-56	59,317	4,564
1956-57	66,890	5,019

acreage and production of sugarcane since 1953-54. However, the per acre yield is rather low, the all-India average being 15 tons (18).

The per capita consumption of sugar and gur in India is very low and falls far short of the requirements for a balanced diet. In 1951-52 the per capita consumption of sugar including gur stood at 26.8 lbs. as against the requirements of 45.6 lbs. per annum as recommended by the Nutrition Advisory Committee. The per capita consumption in 1951 in Australia, the U.S.A., and the U.K. was 129.9, 103.6 and 89.5 lbs. per annum respectively (68). The consumption of sugar and gur has increased steadily during recent years. In 1950-51 under conditions of control about 1,070,000 tons of sugar were consumed. The amount consumed in 1954-55 was about 1,700,000 tons. Imports of sugar into India have not been of a significant order largely due to the continuance of a protective duty up to the end of 1949-50 and the imposition of a revenue duty thereafter. During 1950-51, however, 60,000 tons of sugar were imported as a special measure to ease the difficult internal supply position. During 1951-52 there were no imports of sugar. In 1952-53 the Government arranged for some import of sugar to arrest the rise in prices and to meet the deficit in internal production.

There are two distinct sugarcane belts in India. One is the Indo-Gangetic alluvium in the north which previously grew mostly thin canes (*Saccharum barberi* Jeswiet). These are popularly known as Indian canes and have been extensively cultivated in the country for a long time. They are characterized by high fiber and an intermediate sucrose content. In the second or peninsular belt the thick canes (*Saccharum officinarum* L.) are the chief types. These have all the desirable agronomic and milling qualities. They are characterized by a thin rind and are low in fiber and high in sucrose content. The peninsula is warm in winter, and there is no severe check to the crop. In the northern belt, though the soil is on the whole more fertile, the crop is subject to extreme heat and cold.

The greatest landmark in the sugar industry is the evolution of improved canes in India. Ever since its inception in 1912 the Sugarcane Breeding Institute at Coimbatore has been engaged in the evolution of improved varieties for the sub-tropical regions of India and since 1926 for the tropical regions also. Its program of hybridization has included various species of *Saccharum* and even related genera like *Sorghum, Sclerostachya, Narenga,* and *Bambusa.* The success achieved in the production of improved varieties of cane especially for the subtropics has been largely due to the employment of the wild species, *Saccharum spontaneum* L., as a parent in hybridization. This has resulted in types which are hardy, vigorous, and disease resistant. The improved Coimbatore canes now occupy 90% of the sugarcane area in India. They have increased the yields by at least 50%. Some of the improved types are: Co.290, Co.312, Co.313, Co.419, Co.421, Co.453, and Co.527. Of these, Co.419 yields from 40 to 90 tons of cane per acre and contains 13 to 16% sugar.

Arecanut (*Areca catechu* L.). The arecanut is extensively used as a masticatory throughout India. It is generally chewed with betel leaf (*Piper betle* L.) smeared with a little slaked lime and "katha" obtained by boiling the heartwood of *Acacia catechu* (L.f.) Willd. in water. The palm is a native of Malaya where it is extensively cultivated. In India the crop is concentrated in the southwestern and northeastern parts of the country in regions of high rainfall. The plant thrives on a variety of soils such as the laterite soils of the west coast, the alluvial soils of Bengal and Assam, and the dark fertile clayey loams in the drier parts of Mysore. The range of the mean tem-

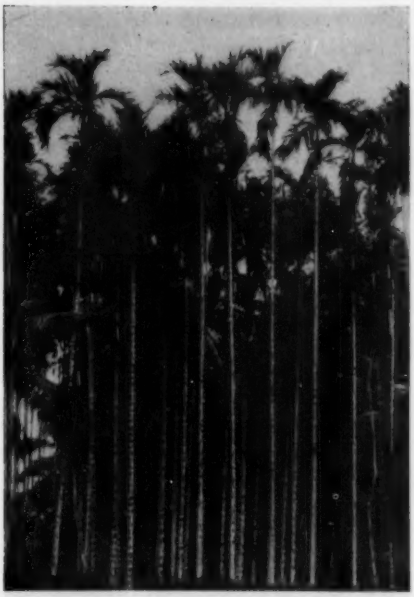

Fig. 4. Trees of arecanut (Courtesy of Indian Central Arecanut Committee, Kozhikode).

perature at which this palm can flourish is 15.5° C. to 37.7° C.

The area under this crop in India measures 260,237 acres (36), and the plant takes about eight to ten years to mature. The existing production is approximately 81,000 tons as compared to the annual requirement of 118,000 tons. A large quantity is, therefore, imported from Malaya, Singapore, and Ceylon. During 1954 arecanuts worth 22.8 million rupees were imported (36). On account of the protection which has been given to the local industry by the imposition of a duty and of a monetary ceiling on the import of arecanuts, prices are better for the locally produced nuts. This has enabled growers to pay a little more attention to the crop. It may be mentioned here that the arecanut, unlike other commercial crops, occupies a peculiar position in that the cultivation of the crop is in the hands of poor farmers with small holdings. These holdings, on an average, do not exceed an acre in area. A small quantity of arecanuts is also exported from India to countries such as Kenya, Pakistan, North and South Rhodesia, and Saudi Arabia.

Copra (*Cocos nucifera* L.). The coconut, a native of the Malay Peninsula, is the most useful of the tropical palms. With an area of 1.58 million acres and production of about 3,800 million nuts a year, India is the second largest coconut-growing country in the world, next only to the Philippines. The bulk of the area in the country lies in the southern zone. About 54% of the nuts are utilized for edible and other household purposes and 46% converted into copra which is the dried kernel of the nut. Prior to the First World War, India was an exporter of copra and coconut oil; but the conditions created by the war and the fillip it gave to the vegetable oil, soap, and toilet article industries in India made it necessary for the country to import large quantities of copra and coconut oil. The Japanese occupation, during the Second World War, of some of the principal coconut-growing countries like the Philippines and Indonesia caused an acute shortage in the supply of copra and coconut oil in India. Accordingly, the Indian Government took steps to intensify the production of coconut so as to make the country self-sufficient in this commodity. The present production of copra is estimated at about 280,000 tons per annum, of which 59,100 tons (21%) is retained for edible purposes and the rest, 221,000 tons, used for the extraction of coconut oil (72). In addition, about 80,000 tons of copra are being imported each year. The present total production of coconut oil in India is estimated at about 180,000 tons (72). Of this, soap manufacture alone consumes about 46,000 tons per annum, and nearly 88,000 tons of oil are used for edible purposes.

Among the forms grown in India, the 'tall' variety yields nuts best suited for

copra and oil production. The 'dwarf' variety, although an early bearer, is uneconomical since the palms are irregular in bearing and produce nuts which give copra of inferior quality. As the coconut palm takes about eight years to start bearing and lives up to the age of about 80 years, the Indian Central Coconut Committee has been arranging for the supply of quality seedlings to coconut growers at a very nominal price.

Rubber [*Hevea brasiliensis* (Willd. ex A. Juss.) Mull.-Arg.]. Rubber was introduced into India from Brazil in 1873. Its cultivation is mainly concentrated in the southern part of the country, more than 90% of the total area of 234 thousand acres under rubber being in Kerala. The bulk of the area comprises small holdings. The present production of 23,444 tons of rubber is quite insufficient for the requirements of the country. In spite of an increase in indigenous production, 6,463 tons of rubber were imported in 1956 against 3,839 tons in 1955 (32). The figures for area, production, and imports of rubber from 1950 to 1956 are given in Table VII.

TABLE VII
AREA, PRODUCTION, AND IMPORTS OF RUBBER

Year	Area (in Thousand Acres)	Production (in Thousand Tons)	Imports (in Thousand Tons)
1950	181.11	15.59	1.08
1951	182.76	17.14	6.92
1952	185.30	19.86	3.85
1953	189.38	21.13	0.27
1954	198.79	21.49	3.37
1955	214.46	22.48	3.83
1956	234.35	23.44	6.46

The average yield (about 250 lbs. of rubber per acre) is the lowest among the rubber-producing countries of the world. This is due to excessive tapping for a long time in disregard of the maintenance and rehabilitation of the plantations. Some of the important measures that have been taken to step up production in the country are: (a) a rubber replanting subsidy scheme has been launched which aims at replanting 70,000 acres of old and low-yielding rubber with high-yielding material at the rate of 7,000 acres a year; (b) an additional area of 50,000 acres is to be brought under new planting. Of this some is earmarked for the conversion of many small and uneconomic holdings into larger units. In addition, a factory is being set up near Bareilly for the production of synthetic rubber.

THE EXPORT CROPS

The export crops are important as a source of earning foreign exchange for the necessary imports. Tea alone earns for India about 800 million rupees of foreign exchange. The export duty forms another major source of revenue for the Government. The export crops provide the raw materials needed to develop new industries and are also a major source of employment for millions of persons. India enjoys a unique position in the world for the export of certain agricultural commodities like tea, jute, lac, tobacco, spices, oilseeds, and cashewnuts. These along with others will now be discussed individually.

Beverage Crops

Tea [*Camellia sinensis* (L.) O. Ktze.]. The tea plant is considered to be a native of Assam and the adjoining areas of Upper Burma; some regard it to be a native of southern Yunnan and Upper Indo-China (73). The major areas of production are concentrated in the northeast region comprising the Brahmaputra and Surma Valleys of Assam and the Darjeeling and Jalpaiguri districts of Bengal. This region accounts for nearly 74% of the total production. In south India, the growing of tea is confined to some elevated areas of Nilgiris, Malabar, Mysore, and Travancore which together account for about 21% of the total production. The total number of plantations, covering an area of 777,167 acres, was reported to be 6,544 in 1952 (69). In 1939 about 84%

of these holdings was run by foreigners, mainly British, but the proportion fell to 64% in 1953. It may be mentioned that the plantation system of agriculture is not native to this country. It was introduced by the British in their colonial days, and in the popular mind it is still associated with foreign rule. While the area under tea has remained more or less unchanged under the international agreement, the production has increased significantly. The total production of tea in 1952 was placed at 675.3 million lbs. as against 641.1 million lbs. in 1951 (69). It is estimated to go up to 726.5 million lbs. in 1957-58 (27).

India is the largest producer and exporter of tea in the world. About 60% of the total produce is exported. The Government declared the export allotment of tea for the year 1957-58 at 460.96 million lbs. (27). The U.K. and the U.S.A. are the two main buyers of Indian tea. In 1955 the U.K. alone imported 249.27 million lbs. although this represented a substantial decline from the quantities imported during 1953 (354.92 million lbs.) and 1954 (326.49 million lbs.). Egypt is another important importer of Indian tea.

The Indian tea industry has passed through alternating periods of prosperity and depression. During the Second World War and the immediate post-war years, India was in a favorable position not only to increase her production but to find a ready market for it abroad. This was due to the fact that most of her competitors had temporarily disappeared from the overseas markets on account of the War. Indonesia, an important producer of tea, was overrun by the Japanese and ceased to export tea. China, Japan, and Formosa could not enter the world markets until after the end of the War. With the exception of Ceylon, India had virtually no competitor. The situation has now changed considerably. The Indonesian plantations are being rehabilitated, and exports from Indonesia, China, and Japan are gradually increasing. Ceylon, too, has increased her production.

Coffee (*Coffea* spp.). Of the three commercially important species of *Coffea* (*arabica, robusta,* and *liberica*), the first two are extensively cultivated in India. *C. arabica,* which is considered to be a native of Abyssinia, was introduced into India through Arabia (73). *C. robusta* is a native of the Belgian Congo and was introduced from Java where it constitutes nearly 85% of the crop (73). The bulk of the coffee grown in India is *C. arabica.* Almost the whole of the area under coffee lies in the southern part of the country.

The Indian *C. arabica,* which is reputed to be one of the best mild coffees in the world, occupies a high position in international trade by virtue of its quality. Before World War II, more than 70% of the coffee produced in the country was being exported (39). More recently, the exports of coffee from India have been limited to the available surplus after meeting the increasing demands of the consumer at home. Nearly 60 to 70% of the total production is now consumed within the country. The production and export of coffee from India are shown in Table VIII.

TABLE VIII
PRODUCTION AND EXPORT OF COFFEE IN TONS

Year	Production	Export
1950-51	18,595	2,677
1951-52	21,235	804
1952-53	23,565	2,128
1953-54	29,555	2,779
1954-55	25,100	10,144

Source — Coffee Statistics relating to India 1954-55. Coffee Board, Bangalore.

During the last three or four years the coffee industry has been doing very well in the country. At least 12 thousand acres have been newly planted, and another 10 to 15 thousand acres have been replanted. The average production per acre has also gone up by at least 100%.

A Plantation Commission was appointed by the Government to make an inquiry into the economic conditions and other problems of tea, coffee, and rubber plantations in India (28). The government has accepted the Commission's recommendation that the extent of the area under coffee plantations should be regulated by the Coffee Board in the interest of the orderly development of the industry. No future planting or replanting of coffee can be done without taking out licenses from the Coffee Board. This is to insure that only suitable areas are taken up for plantation and that approved planting materials are used.

Oilseeds

India is one of the most important oilseed-producing countries in the world. The oilseeds and vegetable oils are also valuable export commodities. The main oilseed crops grown in the country are groundnut, rape and mustard, sesamum, linseed, and castor. Their area and production are given in Table IX. As will be seen from this, the total production of oilseeds increased from 5,705,000 tons in 1955-56 to 6,032,000 tons in 1956-57.

Groundnut (*Arachis hypogaea* L.). Groundnut is the most important of the oilseed crops of India. Although originally introduced into the west coast of India in the sixteenth century, probably by the Portuguese, the crop found its way to the east coast about the middle of the nineteenth century (26). While the area under groundnut in India in 1850 was only 4,000 acres, at present the crop occupies about 13 million acres with an annual production of 4.0 million tons of nuts in shell. India now stands foremost among the nations of the world both in acreage and production of groundnuts, accounting for nearly 41% of the world acreage and about 32% of the world production. The major portion (about 63% of the crop produced in the country is pressed for oil (38) which is used for culinary purposes either as such or in the form of the hydrogenated product (Vanaspati). An important by-product is the seed cake which has a high nutritive value. Besides its use as a concentrated feed for cattle, the cake is also a good nitrogenous manure. The total value of India's export of groundnut oil, seed, and cake during 1955-56 was 218.8 million rupees.

The four important commercial types of groundnut grown in India are 'Coromandel', 'Bombay Bold', 'Spanish Peanut', and 'Red Natal'. The 'Coromandel' and 'Bombay Bold' belong to the spreading type in which the pods are medium-sized and contain one to three oval kernels in a comparatively thick shell; the 'Spanish Peanut' and 'Red Natal' belong to the erect or bunch type in which the pods are usually small and contain one to two small round seeds within a thin shell (8). The bulk of the produce is from the spreading types (26). The bunch types

TABLE IX
AREA AND PRODUCTION OF THE MAJOR OILSEED CROPS

	Area (in Thousand Acres)		Production (in Thousand Tons)	
	1955-56	1956-57	1955-56	1956-57
Groundnut	12,692	13,101	3,862*	4,086*
Rape and Mustard	6,317	6,211	848	1,017
Sesamum	5,653	5,433	457	451
Linseed	3,781	3,758	414	349
Castor	1,405	1,403	124	129
Total	29,848	29,906	5,705	6,032

* In terms of nuts in shell.

are easier to harvest as the pods appear in a cluster around the main axis, but their seeds are non-dormant. The dormant habit has been incorporated into some of these by crossing them with the spreading types (41). The leaf-spot caused by *Cercospora* is an important disease to which the bunchy types are more susceptible than the spreading ones. Some fairly resistant bunchy types such as H.G. 1 have, however, been evolved. Other high-yielding improved strains of groundnut evolved in India are TMV 1, TMV 2, TMV 3, and TMV 4.

Rape and Mustard (*Brassica* spp.). Included here are the oil-yielding brassicas ranking next only to groundnut, both in regard to area and production (Table IX). They are grown in the Gangetic plains mostly mixed with other crops like wheat and gram and sometimes as a pure crop. The species commonly cultivated in India are *Brassica campestris* var. *sarson*, *B. campestris* var. *toria*, *B. campestris* var. *dichotoma*, *B. juncea*, and *B. nigra*. In addition to these, *Eruca sativa*, which is closely related to *Brassica*, is also grown for its oil-yielding seeds. Recent studies by Russian botanists have shown that eastern Afghanistan, together with the adjoining portion of northwestern India, is one of the independent centers of origin of plants of the *B. campestris* group (73). The average yield of seed per acre of the brassica crops is rather low in India and is estimated at 450 lbs. per acre. During 1954-55 India exported 107 tons of seed and 479.9 tons of mustard oil (60).

Sesame (*Sesamum orientale* L.). Sesame accounts for nearly one fifth of the total oilseed acreage in the country. While the plant is a native of Africa, India and Japan are considered to be its secondary centers of origin (46). The crop has been under cultivation in India since very ancient times. On an average, 54% of the sesame crop in India is sown pure, and the remainder is mixed (56). Sesame seed is often used in confectionary and is an important source of edible oil. The oilcake is valuable as a concentrated feed for milch cattle. India was an important exporter of sesame seed and oil in the pre-war years. At present, however, the exports are almost negligible.

Three improved strains of sesame, viz., TMV 1, TMV 2, and TMV 3, produced in Madras, give a 20 to 50% higher yield over the local varieties. The crop is subject in its early stages to the attack of a caterpillar, *Antigastra catalaunalis*, and to the "phyllody" disease which is characterized by the conversion of the floral organs into leafy structures. A wild species, *S. prostratum*, is resistant to *Antigastra* as well as to "phyllody". This has been crossed with *S. orientale* and a fertile amphidiploid produced from the sterile F_1 hybrid. Back crossing the amphidiploid with the cultivated varieties has yielded some useful selections combining good yield and resistance (46).

Linseed (*Linum usitatissimum* L.). Linseed stands fourth among the Indian oilseeds both as to acreage and production. The crop is grown in the Gangetic alluvium and peninsular India. The oil, which is of a drying type, is used in the manufacture of paints and varnishes, oilcloth, linoleum, and other products. It is also used for edible purposes. The seed cake is a good cattle feed. Of late, however, there has been a sharp fall in the export of Indian linseed oil, from 29,049 tons in 1952-53 to 10,118 tons in 1954-55 (60). This is mainly because of the comparatively higher price of Indian oil as compared with that from other exporting countries (61).

The early types of linseed like N.P. 12, N.P. 121, and N.P. 124 produced only small seeds with low oil content. By crossing these with peninsular types, which possess large seeds with a higher oil content, a number of strains were evolved which combined high yield, bold

seededness, and satisfactory oil content. The improved types are, however, susceptible to a rust (*Melampsora lini*). Crosses were, therefore, made between these and some Australian varieties which are immune to the races of rust prevalent in India. Some of the new types thus evolved are N.P. (R.R.) 5, 9, 45, 262, 439, and 440 (17).

Castor (*Ricinus communis* L.). The crop is cultivated for the seed which yields the castor oil of commerce. This finds extensive use as a lubricant and is also used for lighting and in medicine. The castor cake is a valuable fertilizer. Besides having a high nitrogen content, it acts as a soil disinfectant (54). Castor is raised mostly as a rain-fed crop in the kharif season and comes up well even under extremely varied conditions of soil and climate.

Next to Brazil, India is the largest producer of castor in the world. The average annual production of castor seed in India during 1951-56 was estimated at 112,000 tons (64). About 94% of the produce is utilized for the extraction of oil and the remainder for seed. The production of oil in 1955-56 and 1956-57 was 43,000 tons and 45,000 tons, respectively. The export of castor oil in 1954-55 and 1955-56 was 32,171 tons and 38,936 tons, respectively (64).

Niger [*Guizotia abyssinica* (L.f.) Cass.]. Although niger is not a major oilseed, India holds almost a monopoly of it. The area under the crop is over 700,000 acres, and the annual production is estimated at 75,000 tons (73). The plant is generally cultivated in the hilly tracts. It comes up well in lateritic and light loamy soils and is generally raised as a mixture with pulses and other kharif crops. The oil is used in cooking, for anointing the body, as an illuminant, and in the manufacture of paints (56). The oil-cake is a rich concentrate for milch cattle. Whereas the export of niger seed in 1952-53 was 20,783 tons, during 1954-55 it decreased to 7,534 tons (60).

Condiments and Spices

The quest for condiments and spices was once a powerful force in world history. The search for a sea route to the Spice Islands of the East led to the voyages of Columbus, Magellan, and many others. India is one of the largest suppliers of condiments and spices. Some of the more important of these are discussed below:

Black Pepper (*Piper nigrum* L.). A native of the Malabar coast of India, pepper is perhaps the most important spice from the international point of view. The dried berries of the vine furnish the black pepper of commerce. Removal of the skin gives white pepper. The plant is cultivated in southwest India on an area of about 234,000 acres. With an annual production of 32,000 tons (3), India has remained a notable supplier of pepper to the world market. In the nineteenth century, pepper cultivation was extended to the Malayan Archipelago which became another significant source of this valuable spice. However, during World War II there was a large-scale destruction of pepper plantations in Indonesia so that India remained the only important producer of this spice. The exports in 1951-52 were well over 230 million rupees. In recent years, however, Indonesia has started rehabilitating its pepper industry.

Chili (*Capsicum frutescens* L.). A native of tropical America, the plant was introduced into India only about the middle of the seventeenth century. Nevertheless, it now occupies a significant place among spices in the country and is more popular than pepper. Chilis in India are consumed both in the green and the dried condition. The dried fruits are also used in the powdered form. The so-called

curry powder is made by grinding roasted dry chilis with other condiments such as coriander, cumin, and turmeric. The area under chili in India measures 1,450,000 acres, with an annual production of 354 thousand tons (3). On an average, 6,820 tons of dry chilis are exported annually (62).

Cardamom [*Elettaria cardamomum* (L.) Maton]. The cardamom consists of the dried capsules of this plant which is indigenous to south India (55). The seeds are used as a masticatory either alone or with betel leaf, as a spice for flavoring sweet dishes, and as a carminative. There are two botanical varieties (13): *E. cardamomum* Maton var. *major* Thw., with larger fruits but a shorter flowering panicle; and *E. cardamomum* Maton var. *minuscula* Burkill with smaller fruit and a longer panicle. With an area of about 120,000 acres the average annual production of cardamom ranges between 1,750 to 2;000 tons (73). India earns about 16 million rupees of foreign exchange annually by exporting cardamom to other countries. The U.K., Arabia, the U.S.A., Sweden, Norway, and Denmark are the chief importing countries. The average pre-war exports from India amounted to 716 tons, which increased during the post-war period to 917 tons representing 82% of the international trade (49). The spicy aromatic seeds of *Amomum subulatum* Roxb., called greater cardamom, are a cheaper but inferior substitute for the true cardamom.

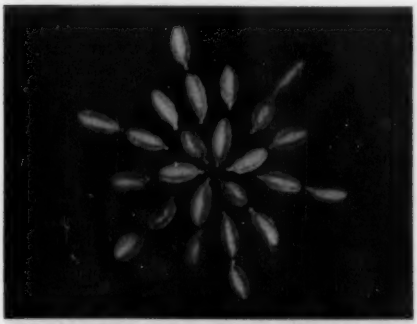

Fig. 5. Fruits of true cardamom (*Elettaria cardamomum*).

Fig. 6. Fruits of greater cardamom (*Amomum subulatum*), inferior substitute for the true cardamom.

Turmeric (*Curcuma longa* L.). The plant is a native of southern Asia. The powder obtained by grinding the rhizomes is used as a condiment. The total acreage under turmeric in India has been estimated variously from 60,000 to 100,000 acres, and the production is nearly 100,000 tons of rhizome per annum (73). A large part is consumed within the country, but a portion is exported to Pakistan, Ceylon, the U.K., and the U.S.A.

Ginger (*Zingiber officinale* Rosc.). Although a native of tropical Asia, it is one of the earliest of the oriental spices to become known to western countries. It is usually raised as a monsoon crop, and the immature and dried rhizomes constitute the ginger of commerce. About 48,000 acres are under the crop, and the estimated production of cured ginger is 24,000 tons of which about 18,000 tons are produced on the west coast alone (50). About 25% of the produce on the west

Fig. 7. The immature and dried rhizomes of *Zingiber officinale* constitute the ginger of commerce (Courtesy of Indian Council of Agricultural Research, New Delhi).

coast is sold as green ginger and the rest made into dry ginger and exported to other countries. The chief countries which import ginger from India are the U.K., the U.S.A., France, Germany, and Arabia.

Coriander (*Coriandrum sativum* L.). The mature and dried fruits are widely used as a condiment. The green leaves of the plant are added to vegetables for flavor. Most of the coriander is consumed within the country, and only a small quantity is exported, chiefly to Ceylon, Straits Settlements, Malaya, and East Africa.

Cumin (*Cuminum cyminum* L.). The cumin[7] seeds of commerce, 'really fruits', are used as an essential ingredient of all mixed spices and curry powders, for flavoring soups, sausages, pickles, and cheese, and for seasoning bread and cakes. In indigenous medicine cumin seeds have long been considered as a stimulant and carminative. A small quantity of cumin is exported from India to Ceylon, Straits Settlements, Malaya, and East Africa.

Fennel (*Foeniculum vulgare* Mill.). The dried fruits, which have a fragrant odor and a pleasant aromatic taste, are used as a masticatory either as such or with betel leaf. They are also used for flavoring soups, bread rolls, and in confectionery. The produce is largely consumed within the country, but a small quantity is being exported to Pakistan, Ceylon, Burma, Malaya, Kenya, Sweden, the U.K., France, and the U.S.A.

In addition to the condiments and spices described above, a number of others are grown in the country. These include nutmeg (*Myristica fragrans* Houtt.); cinnamon (*Cinnamomum zeylanicum* Breyn); clove [*Syzygium aromaticum* (L.) Merr. et Perry]; bay leaf (*Cinnamomum tamala* Nees); dill (*Anethum graveolens* L.); ajwan [*Trachyspermum ammi* (L.) Sprague] and a few others.

Fiber Crops

Jute (*Corchorus capsularis* L., *C. olitorius* L.). Next to cotton, jute is the most important fiber crop in India. Its main area of cultivation lies in the north-eastern region of the country. It is a rainy season crop being sown in April and May and harvested in July and August. The plants thrive best in damp heat, and the soil most suited to their growth is loam or sandy loam. *Corchorus capsularis* is known to be wild in south China, while *C. olitorius* is considered to be indigenous. Being early maturing, *C. capsularis* is grown more widely as it can be followed by transplanted paddy. About 75% of the jute land in India is under *C. capsularis* (63). Although the early types give a superior quality fiber, they are usually low yielders. The late maturing types normally yield more, but the fiber is of inferior quality. A number of strains have been evolved to suit the different environmental conditions of the jute-growing areas of the country. The two improved types in *C. capsularis* are C-212 and C-321. While C-212 is a late type with good yield and better quality fiber, C-321 is an early maturing type with fibers of very good quality. The improved types in *C. olitorius* are 0-620, 0-632, and 0-753. These are gradually replacing 'Chinsurah Green' which occupies nearly 75% of the *C. olitorius* area. Of all the three, 0-620 is specially reputed for its excellent fiber quality.

Before partition, India had a virtual monopoly in the production and supply of raw jute. After partition, only about 19% of the total production of raw jute of undivided India came to the share of the Indian Union. The present area under jute (1.88 million acres) is nearly three times the area under this crop in 1947-48. While there was an increase in

[7] The seeds of *Nigella sativa* L., called black cumin, are also used as a spice and for flavoring curries.

The industry is not only a sustainer of west coast economy but also a substantial earner of foreign exchange for the country. Coir and coir goods such as matting rugs account for about 80 to 100 million rupees in India's foreign exchange (4). With an annual production of nearly 120 thousand tons, India is the largest producer of coir in the world (4). About 50 000 tons of coir yarn are annually exported to the U.K., Holland, Germany, Switzerland, the U.S.A., Canada, and some other countries.

Essential Oils and Medicinal Crops

Lemongrass Oil [*Cymbopogon citratus* (D.C.) Stapf.]. This plant is indigenous to India, and the oil is used in perfumery, soaps, and cosmetics, and as a mosquito repellent. India is the principal producer of this essential oil, the annual estimated production being about 800 tons. The oil is exported mostly to the U.S.A., the U.K., France, Germany, the Netherlands, and Switzerland, and only a small quantity is consumed within the country.

Palmarosa Oil [*Cymbopogon martini* (Roxb.) Stapf.]. This plant is used for several perfumes and cosmetics. Until recently, India was the only source of supply of palmarosa oil. A small quantity is now produced in Java from plants introduced from India. Large quantities of the Indian palmarosa oil are exported to Red Sea ports and Egypt for use in perfumery.

Psyllium (*Plantago ovata* Forsk.). Commonly known as "isubgol" in India, this seed is mainly valued for its husk which is a popular household remedy for dysentery, chronic constipation, and other intestinal troubles. Although its use has slightly declined in India owing to the increasing use of allopathic medicines, there is an increased export demand particularly from the U.S.A. where isubgol seed and husk are used as a laxative. Small quantities are also shipped to other countries including the U.K., Belgium, and Canada. About 75% of the Indian produce is exported (7). France seems to be the only serious competitor of India in this field. The French product which consists of the seed and husk of *Plantago psyllium*, although very similar in appearance and properties to *P. ovata*, is considered inferior to the latter.

Miscellaneous Crops

Tobacco (*Nicotiana tabacum* L. and *N. rustica* L.). The original home of tobacco is in South America. It was introduced into India by the Portuguese in the beginning of the seventeenth century. Today, next to the U.S.A. and China, India is the largest tobacco-producing country in the world with an area of 921 thousand acres under the crop. Approximately 259 thousand tons of tobacco are produced annually (70), and the foreign exchange earned from its export in 1955-56 amounted to 120 million rupees (70). By way of excise duty, tobacco contributed another 330 million rupees in the same year. In addition, an annual income of about 900,000 rupees is derived from the agricultural cess levied on the export of unmanufactured tobacco. The area, production, and exports of unmanufactured tobacco from India are given in Table X.

TABLE X
AREA, PRODUCTION, AND EXPORTS OF TOBACCO

Year	Area (in Thousand Acres)	Production (in Thousand Tons)	Exports (in Thousand Tons)
1950-51	883	257	42
1951-52	713	206	45
1952-53	896	241	34
1953-54	912	268	31
1954-55	846	244	38
1955-56	921	259	40

Two species are grown, *Nicotiana tabacum* and *N. rustica*. About 25% of the total tobacco area in India is under

the production of jute from 1.7 million bales of 400 lbs. each in 1947-48 to about 4.0 million bales in 1955-56, much of the additional jute produced in the country was of poor quality which brought a low price. The quantity of raw jute and its manufactured products exported in 1949-50 was 925,000 tons (73), but since 1950-51 there has been practically no export of raw jute owing to its increasing demand within the country itself. The present requirement of raw jute is estimated at 7.2 million bales if all the mills were to work to full capacity (66).

Sunn Hemp (*Crotalaria juncea* L.). As a bast fiber crop, sunn hemp ranks next in importance to jute. The fiber is used mainly for making ropes. It is also suitable for fishing nets and maritime cordage because of its resistance to the deleterious action of water (33). Indian sunn hemp found its way to the European markets toward the end of the seventeenth century. Before the outbreak of World War II, the U.K. and Belgium were our principal buyers (10), although Germany, Greece, and Italy also took appreciable quantities. The exports to the U.S.A. were comparatively small in the pre-war years but have increased recently. Standard specifications were prescribed in 1942 for various grades of the different types of sunn hemp, and since then exports of ungraded sunn hemp have been prohibited.

Kapok [*Salmalia malabarica* (DC.) Schott & Endl.]. The word kapok is used for the floss obtained from the fruits of *Ceiba pentandra* (L.) Gaertn. as well as *Salmalia malabarica*. The fiber finds use in bedding and upholstery, in the production of naval life-saving appliances, and in the construction of thermally insulated and sound proof covers and walls. Indian kapok is mostly that from *Salmalia* whereas the Javan product is obtained from *Ceiba*. Indian kapok is very similar to Javan kapok except that it is slightly more brownish. *Salmalia* is found in practically all parts of the country, while *Ceiba* is found mainly in the forest areas of Western Ghats. *Salmalia* or "Semal" trees reach their full bearing capacity when they are about ten years old, although they may start producing fruits at the age of five or six years. The yield of floss with seed is estimated to range from 10 to 40 lbs. per tree (9). The trees flower during January and February, and fruits are plucked with the help of hooks attached to long poles. Although kapok starts coming to the market toward the end of March, May and June are the peak months when more than 65% of the total produce is reported to be in the market.

India ranks next only to Java as a world supplier of kapok. The total annual production of kapok floss in the country has been estimated at 3,306 tons (9). Indian kapok is sometimes adulterated with cotton waste and akund (*Calotropis* sp.) floss. These admixtures make kapok quite unfit for use in the manufacture of naval life-saving appliances.

Akund (*Calotropis* spp.). Akund floss is obtained from the seeds of *Calotropis procera* and *C. gigantea*, mainly the former. Both the species grow wild in different parts of the country. The total annual production of cleaned floss in India is estimated at about 300 tons. Out of this, approximately 160 tons are exported and the balance used in the country for stuffing pillows and mattresses and also for admixing with kapok. Australia and New Zealand are the chief markets for the Indian akund floss (9).

Coir (*Cocos nucifera* L.). The coir industry is one of the important cottage industries of India. The various processes such as the collection of husks of coconuts, their retting, the extraction of the fiber, and the spinning of yarn from the coir are largely carried out by small units.

nuts, India is now the largest cashewnut-producing country in the world (51). Nearly 90% of the international trade in cashew kernels and cashew shell oil is monopolized by India. About 75% of the Indian produce is exported, the chief buyers being the U.S.A. and the U.K. The cashew oil is employed as a waterproofing agent and a preservative in the painting of boats, fishing nets, and light woodwork. India earned 126.9 million rupees by the export of cashewnut and cashew oil in 1957 (12).

The plant is very hardy and drought resistant and thrives under a variety of soil conditions. In spite of its numerous virtues it is essentially a waste land crop in India, and its cultivation on plantation scale has been attempted only recently. It is grown chiefly in the coastal parts and nearly 70% of the production is from the west coast between Bombay and Cape Comorin.

There are more than 16 factories for the processing of cashewnut to extract the edible kernel. The grading of the nuts is done according to American standards, based on "counts" or number of kernels per pound. The kernels which have not split are separated as "wholes". These are classified into six classes with 210, 240, 280, 320, 400, and 450 whole kernels to the pound. The Government is taking steps to devise measures to encourage the extension of the area under cashewnut and to improve the marketing and other commercial aspects of the crop.

Lac. India accounts for nearly 85% of the world production of lac (30). Besides, much of the produce of Thailand,

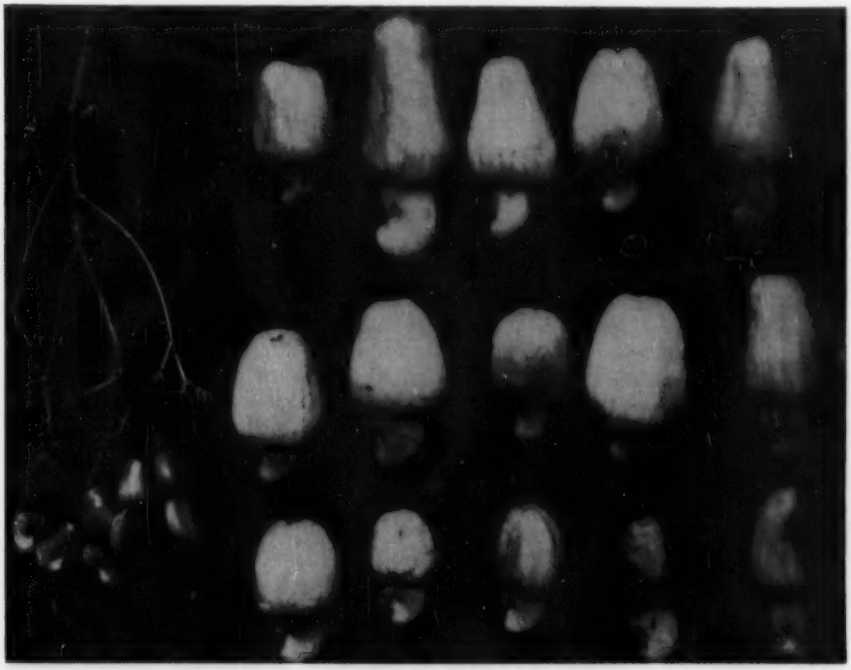

Fig. 8. Fruits of cashewnut, an important dollar earning crop of India (Photo by Mr. V. N. Madhava Rao, Central Cashewnut Research Station, Mangalore).

rustica. Since this requires a cooler climate, it is mainly confined to the northern and the northeastern parts while *tabacum* is grown all over the country. The varieties under *tabacum*, usually with pink flowers, are tall with long and broad leaves. On the other hand, the *rustica* varieties are short with round and puckered leaves and have yellow flowers. While *N. tabacum* is grown for the manufacture of cigarettes, cigars, cheroots, "bidi"[8], chewing, snuff, "hookah" (hubble-ubble), and pipe tobacco, *N. rustica* is used mainly for 'hookah", chewing, and snuff. The bulk of the area under cigarette tobacco in the country is at present under one variety, 'Harrison Special', originally introduced from America. One selection, 'Amarelo 5', proved superior to 'Harrison Special' both in the time taken for curing and the percentage of first grade yellow leaf. A new variety, 'Chatham', superior to 'Harrison Special' in yield and quality has recently passed the final stages of field trials and is being distributed to replace 'Harrison Special' (29). The area under cigarette tobacco is nearly 200,000 acres, most of which is concentrated in the Andhra State (south India). About 22,000 million cigarettes are manufactured annually in India, and practically the entire industry is owned by foreigners (29). The manufacture and consumption of hookah tobacco is almost entirely confined to the northern part of the country. Two high-yielding selections, N.P. 219 and N.P. 220, have been evolved through inter-varietal hybridization. Many centers in northern India, particularly Lucknow, Banaras, and Delhi, are famous for the manufacture of chewing tobacco products. These are prepared either in the form of small dry pills or flakes, highly flavored and rolled into silver or gold leaf. The improved strains of chewing tobacco evolved in the country are N.P. 18 and N.P. 70. The annual area under bidi tobacco is estimated at about 210,000 acres, representing nearly one fourth of the total acreage in the country. Keliu (K. 49) and surti (S. 20) are the two improved strains of bidi tobacco.

If India's share in the total world trade of tobacco fails to correspond with its position as the third largest producer of this crop, this is mainly because over 75% of the indigenous production consists of hookah, bidi, and chewing types which have very little demand in the international markets. The U.K. is the biggest purchaser of Indian tobacco. During 1955-56 the U.K. imported about 13 thousand tons of raw tobacco from India. Other important outlets for Indian tobacco are Japan, Aden, Ceylon, the Netherlands, Hong Kong, and the U.S.S.R. Among exported types the chief are flue-cured Virginia, sun-cured Virginia, white Burley, sun-cured Natu and bidi tobacco (43). Among these the Virginia tobacco accounts for more than 75% of the exports. Since 1945 there is a system by which the export of tobacco is prohibited unless the produce is graded and marked in accordance with the rules framed under the Agricultural Produce Act of 1937 (58). The Government has taken keen interest in developing the export trade of tobacco by sponsoring delegations and rendering assistance to tobacco merchants in their foreign tours in quest of markets for Indian tobacco. The country imports small quantities of unmanufactured tobacco required for blending purposes in the manufacture of high class cigarettes. About 1,800 tons of raw tobacco are imported annually, mainly from the U.S.A., for this purpose.

Cashewnut (*Anacardium occidentale* L.). A native of South America, the plant was introduced into India about 400 years ago by the Portuguese. With an annual production of about 60,000 tons of raw

[8] The chief ingredients of a bidi are the wrapper leaf (usually *Diospyros melanoxylon*) and a cheap tobacco filler. Bidis are smaller in size and much cheaper than cigarettes.

Burma, and Singapore is sent to India in the form of stick lac for processing into seed lac and shellac. The industry provides a means of livelihood to numerous families who collect lac from trees in villages and is a source of employment to over 20,000 workers engaged in processing of stick lac into seed lac and shellac. The estimated production of lac in 1955-56 was 99 million lbs., and the industry's contribution to foreign exchange is on an average 150 million rupees per year. Of the different types of lac products exported from the country, shellac is by far the most important. The largest buyers of Indian lac products are the U.S.A., the U.K., and Germany.

The main problems of the industry are the wide fluctuations in price, absence of proper quality control, and the lack of an adequate internal demand for its products. Steps are being taken to improve the position.

Summary of Export Crops

The foregoing account of the major export agricultural commodities of India places us in a better position to understand and gauge their importance. About 1,500 million rupees are earned annually by the export of tea, pepper, groundnut, tobacco, and coir. India is also the principal supplier of certain commodities like the cashewnut, lac, lemongrass oil, palmarosa oil, and psyllium to world markets. There is room for further development of the export trade in a number of items, especially cardamom, pepper, lemongrass oil, kapok, and psyllium. The diversification in the kinds of goods that are being exported places India in a better position than some of the other underdeveloped countries which have often to rely on only two or three primary export commodities.

In recent years India has been facing increasing competition from other countries in the export trade of black pepper. The objective under the Second Five Year Plan is to raise the area under pepper by about 50 thousand acres (66). Coffee is another plant playing an important role in the foreign trade of India. The Indian Coffee Board plans to increase the production of coffee from 25,000 tons to 48,000 tons within the next fifteen years. Of this increase about 10,000 tons are proposed to be secured from intensive cultivation and rehabilitation of existing estates and 13,000 tons from reclamation and fresh plantations (66). Cashewnut is one of the important dollar earners for India. Although cashewnuts are collected on a commercial scale in a few other countries, notably East Africa, the processing of cashew is practically an Indian monopoly. The Government proposes to increase the production of cashewnuts from 60 thousand tons to 80 thousand tons by the end of 1960-61 (66).

THE GOVERNMENT AND DEVELOPMENT

The main object of public policy and of national endeavor in India since independence has been the promotion of rapid and balanced economic development. The First Five Year Plan of the Government for the development of the country ended in 1956. It has laid the foundations for achieving the socialist pattern of society. The national income over these five years has increased by about 18%. The First Five Year Plan accorded a significant place to programs for agriculture and community development. The increase in agricultural production which has taken place since 1952-53 has helped to end inflation and stabilize the economy. The overall index of agricultural production, with 1949-50 as base, stood at 114 in 1953-54 and 1954-55. The agricultural programs of the Second Five Year Plan (1956-61) are intended to provide adequate food for the increased population, the raw materials needed for a growing industrial economy, and larger exportable surpluses of agricultural commodities. The Second Plan thus implies, even more than the First, a close interdependence between agriculture and in-

TABLE XI
DISTRIBUTION OF THE FIRST AND SECOND PLAN OUTLAY

	First Five Year Plan Total provision [In Rs (Million)]	Per cent	*Second Five Year Plan* Total provision [In Rs (Million)]	Per cent
1. Agriculture and Community Development	3,570	15.1	5,680	11.8
2. Irrigation and Power	6,610	28.1	9,130	19.0
3. Industry and Mining	1,790	7.6	8,900	18.5
4. Transport and Communications	5,570	23.6	13,850	28.9
5. Social Services	5,330	22.6	9,450	19.7
6. Miscellaneous	690	3.0	990	2.1
Total	23,560	100.0	48,000	100.0

Source — Second Five Year Plan. Planning Commission, Government of India. 1956.

dustrial development. There is an inevitable shift in priorities with a large emphasis on industralization, especially the development of heavy industry. The total development outlay of the Second Plan works out at 48,000 million rupees.

As will be seen from Table XI, in the Second Plan 19% of the total outlay of the Central and State Governments is to be devoted to irrigation and power and another 12% to agriculture and community development. The aggregate expenditure under these two heads works out at 14,810 million rupees. Although there is a relative shift in priorities between agriculture and industry, increased production of food and raw materials must remain a major consideration not only for the Second Plan period but for several years to come. The demand for food and raw materials is bound to increase rapidly as industrialization proceeds and incomes increase. The principal targets of agricultural production for the Second Five Year Plan are set out in Table XII.

The progress of the programs relating to agricultural production was reviewed by the Standing Committee of the National Development Council in January, 1958. In the report submitted to the Council, it was stated that the targets of production set for the Second Plan were the minimum required for its success and that it was essential to pursue the agricultural production program with a sense of national urgency (5). The Standing Committee took stock of the agricultural

TABLE XII
PRINCIPAL TARGETS OF AGRICULTURAL PRODUCTION DURING THE SECOND PLAN PERIOD

Commodity	Unit	Estimated Production in 1955-56	Target of Additional Production	Estimated Production in 1960-61	Percentage Increase
Food grains	million tons	65.0	10.0	75.0	15
Oilseeds	„ „	5.5	1.5	7.0	27
Sugarcane (*gur*)	„ „	5.8	1.3	7.1	22
Cotton	„ bales	4.2	1.3	5.5	31
Jute	„ „	4.0	1.0	5.0	25
Coconut (oil)	„ tons	0.13	0.08	0.21	62
Arecanut	thousand „	81.0	18.0	99.0	23
Black pepper	„ „	26.0	6.0	32.0	23
Cashewnut	„ „	60.0	20.0	80.0	33
Tea	million pounds	644.0	56.0	700.0	9
Lac	„ „	98.7	32.9	131.6	33

Source — Second Five Year Plan. Planning Commission, Government of India. 1956.

situation and emphasized that the country could not afford to think in terms of importing food grains year after year and that a nation-wide campaign for carrying out the agricultural production program embodied in the plan was vital.

The value of commercial inorganic fertilizers like ammonium sulphate and the superphosphates is well recognized in modern agriculture. The Government has taken steps for their large-scale manufacture. Built at a cost of 230 million rupees and with a productive capacity of 960 tons per day, the Sindri fertilizer factory is the largest of its kind in Asia. The Government is operating a trading scheme known as the Central Fertilizer Pool which aims to ascertain the requirements of the States and of consumers, to procure the quantities needed, to fix prices, and to make the necessary arrangements for the distribution of the fertilizers. During 1957-58, about 800,000 tons of sulphate of ammonia were alloted by the Pool to the State Governments and other interests (3). This represents a great increase over the distribution from the Pool in the past as shown by the following figures: 1954-55, 452,000 tons; 1955-56, 546,000 tons; 1956-57, 585,000 tons; 1957-58, 800,000 tons (3). The distribution of the new fertilizers, urea and ammonium sulphate nitrate, has also registered a sharp increase over the past few years (Table XIII).

TABLE XIII
QUANTITY OF UREA AND AMMONIUM SULPHATE NITRATE (IN TONS) DISTRIBUTED FROM THE CENTRAL FERTILIZER POOL

Year	Urea	Ammonium sulphate nitrate
1955-56	7,000	8,750
1956-57	17,000	20,750
1957-58	58,000	32,000

Source — Agricultural Situation in India, 12: 1354. 1958.

The consumption of nitrogenous fertilizers is proposed to be raised during the Second Plan from 610,000 tons in 1955 to over 1.8 million tons (66).

The Government had allocated 6,610 million rupees and 9,130 million rupees for irrigation and power in its First (19) and Second Five Year Plan (66), respectively. During the period of the First Plan, ten million acres of land were brought under irrigation from minor works and about 6.3 million acres from large and medium irrigation schemes. During the Second Five Year Plan another 21 million acres of land are expected to receive irrigation. Small and medium irrigation works have an important part to play as they provide a large amount of dispersed employment. Further, they involve a smaller outlay and can be executed in a comparatively shorter time.

The Government is taking steps for the development of cooperative farming by which small holdings will be pooled and cultivated jointly to increase the size of the operational unit and make the economies of large-scale organization available, leading ultimately to cooperative village management. Other land reforms (37) in the country include: (1) abolition of intermediaries; (2) regulating the landlord-tenant system by fixing fair rent; conferring security of tenure upon tenants, subject to the landlord's right to resume a limited area for personal cultivation; bringing tenants into direct relationship with the State in respect to areas which the landlord is not entitled to resume and conferring ownership upon them; (3) redistribution of land by placing a ceiling upon existing holdings and future acquisitions and acquiring surplus areas above the ceiling for resettlement of landless agricultural workers.

Realizing the importance of the distribution of pure and improved seed to the farmers, the Government has made provision for the establishment of 4,185 seed farms during the Second Plan period. The number of seed farms actually established during 1956-57 was 343. During the second year of the Plan, 1,416

seed farms were expected to be set up, but the number actually established is understood to be 1,094 (5). The progress in this direction has thus not been very satisfactory. It is expected that every national extension service block will be served by a seed farm and a seed store. The GMF inquiry committee recommended that the National Extension Service organization should be extended all over the country as this is the best way in which India can attempt a solution of the tremendously difficult problem of raising the level of rural life (57). Work along these lines is also being done under the Indo-U.S. technical assistance program and the Ford Foundation. These community projects cover the entire field of rural life: irrigation, supply of good seeds and fertilizers, formation of co-operative societies, cottage and small-scale industries, health and education. In all, during 1957-58, the community development program has served 276,000 villages with a population of 150 million. The Government has allocated 2,000 million rupees for the development of national extension and community projects for the period 1956-61.

In 1928 the Royal Commission on Agriculture in India drew attention to the deplorable agricultural marketing conditions in the country and made a number of recommendations for improving the situation. As a result, the Government constituted the Directorate of Marketing and Inspection in 1935. To give stability to the grades the Agricultural Produce (Grading and Marking) Act was passed in 1937. The Act provides for the fixation of grade standards for agricultural and other products and for the grant of certificates of authorization to suitable private persons or corporate bodies to undertake grading on the basis of these "Agmark" standards. The value of the products graded had risen from a little over ten million rupees in 1940 to more than 170 million rupees in 1953 (20). It is the compulsory grading schemes for sunn hemp and tobacco which have been responsible for the development of fresh foreign markets for these commodities in addition to the stabilization of the existing markets.

The advantages of power-driven machinery in agriculture are being gradually realized in India. A Central Tractor Organization was started in 1946 by the Government. About 2.5 million acres of land were reclaimed during 1951-55 through the Central and State Tractor Organizations. During 1956-61 the Government proposes to reclaim 1.5 million acres of land and to carry out land improvement measures over an area of about two million acres chiefly through the use of tractors.

SUMMARY AND CONCLUSIONS

Agriculture has been the principal economic occupation in India from time immemorial. About 70% of the present population is dependent upon agriculture and more than 50% of the country's national income is contributed by this sector. Although about 78% of the total gross cropped area in India is under food crops, the major problem is still the increase of food production. While the population in 1951 showed an increase of nearly 82 million over that in 1931, there was no appreciable change in the production of food grains during that period. The total food grain production of the country in 1956-57 was 57,251 thousand tons. The production of rice, which is the most important cereal consumed in the country, went up from 26.8 million tons in 1955-56 to 28.1 million tons in 1956-57. India's annual requirements of both rice and wheat exceed her production, and the deficit is met by imports. Sorghum, maize, pearl millet, barley, and finger millet are some of the less important cereals of India. Pulses form an important item supplying a major part of the protein requirements of a country where most people are vege-

tarians. About 15% of the cultivated area in India is under pulses of which gram, pigeon pea, black gram, green gram, lentil, and peas are the most important. The total production of pulses in India during 1956-57 was 11,435 thousand tons.

The commercial crops, which provide the raw materials for industries, account for 17% of the cropped area. The cultivation of cotton and its manufacture into textiles have been practiced in India since prehistoric times. India produced 4.7 million bales of cotton in 1956-57. The favorable supply position of cotton in recent years has led to a decline in the quantity imported into India. Thus, whereas the import in 1950-51 was .81 million bales, in 1954-55 it was only .62 million bales. Further, these imports are mainly confined to such long staple cotton as cannot be produced in the country. A small quantity of short staple cotton is also exported from India. The sugar industry is the second largest industry in the country. The major portion of the cane produced in India is utilized for the manufacture of gur (jaggery). The production in 1956-57 in terms of gur and sugar was 6.74 million tons and 2.02 million tons, respectively. Imports of sugar into India in recent years have not been of a significant order.

The export crops are an important source of foreign exchange for the country. In addition, they contribute a substanial revenue to the Indian Government and are also an important source of employment for millions of Indians. Some of the important items of export are tea, tobacco, lac, black pepper, groundnut, cardamom, coffee, cashewnut, coir, castor oil, and lemongrass oil.

The Government has been making serious efforts for the development of agriculture. The First Five Year Plan (1951-56) accorded a place of pride to programs for agriculture and community development. In the Second Five Year Plan, agricultural programs are intended to provide adequate food to support the increasing population and the raw materials needed for a growing industrial economy and also to make available larger exportable surpluses of agricultural commodities. Although there is a relative shift in priorities between agriculture and industry, increased production of food and raw materials must remain a major consideration for several years to come.

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Recent Highlights in the Chemurgy of Xerophytic Plants[1]

The practical economy of the utilization of the xerophytic plants is dependent upon a fairly complete utilization of the extractives of the particular species involved. For example, agaves (century plants) yield fiber, sapogenins, and some miscellaneous extractives, which vary with the species.

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I. Introduction

Since the author's first review (35) of the subject of the potential industrial utilization of xerophytic, or drought-resisting, vegetation native to the U. S. Southwest and Mexico, much progress has been made toward making an industry based upon these raw materials an accomplished fact. Despite this, the surface of the available potential has only been scratched. It should again be emphasized that serious thought should be given to sources of raw materials which not only are domestic, but which are replenishable. Certainly, the field of xerophytic plant chemurgy has much to recommend it in this respect. The plants involved (cacti, yuccas, agaves or "century plants," etc.) will grow under adverse condition, with a minimum of attendant labor, and on marginal land. This discussion will highlight the newer developments in this field and will bring up to date many of the economic factors involved.

[1] A paper presented at the Symposium on Chemical Industry and Opportunities in Mexico, 14th Regional Southwest Meeting, American Chemical Society, San Antonio, Texas, December 5, 1958.

II. Survey of Recent Highlights in the Field of Xerophytic Plant Chemurgy

A. Pharmaceuticals

1. Steroids. Since the discovery that cortisone steroids would relieve arthritis, the search for cortisone or its precursors has been both intensive and extensive. Earlier characterization of the various steroidal sapogenins was done by Marker and co-workers (105) at Pennsylvania State University, State College, Pa. Subsequently, a joint effort was initiated between the Specialty Crop Introductions Unit at Beltsville, Md., and the Eastern Regional Utilization Bureau at Philadelphia, Pa., both of the Agricultural Research Service, U.S.D.A. Thanks to these two groups, under Donovan Correll at Beltsville and Monroe Wall at Philadelphia, numerous steroidal sapogenins, which are convertible to cortisone, have been discovered in these plants. Yucca (Liliaceae) and agaves (Amaryllidaceae) were the two principal plant types investigated (32).

The criterion for determining the initial desirability of any given steroid as a cortisone precursor is that the compound must have hydroxyl groups in the 3- and 11-positions, or be readily convertible to

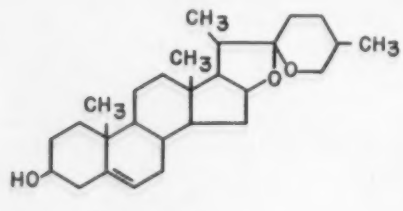
this structure. The outstanding steroids for cortisone production are diosgenin, sarsasapogenin, hecogenin, and tigogenin. The formulas of these materials are presented in Fig. 1.

The steroidal sapogenins are currently being screened as cancer therapeutics by Mary Caldwell and associates at the University of Arizona. Earlier work by Taylor, McKenna, and Burlage (141) had indicated that extracts of yucca roots inhibited tumor growth in the aminopterin range, without affecting embryo growth. Such extracts would undoubtedly contain sapogenins.

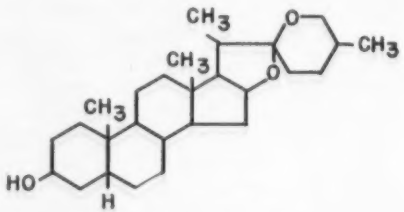
Although the Mexican yam (*Dioscorea floribunda* Mart. and Gal.) is considered by the U. S. Department of Agriculture to be the best source of steroids, it is also stated by them that cultivation of agaves having good fibers, plus sapogenins, offers the opportunity of an entirely new fiber and chemical industry (32). The species recommended for cultivation were *Agave fourcroydes*, *Agave zapupe*, and *Agave sisalana*. In Mexico, additional consideration might well be given to *Agave mescal* Koch, since this species is already under cultivation in Jalisco (near Guadalajara) as a source of raw material for tequila and allied beverage products.

Wall and his associates (92-94, 121-124, 146-158) have intensively studied the isolation and structure proof of the steroids and analytical and identification methods for them.

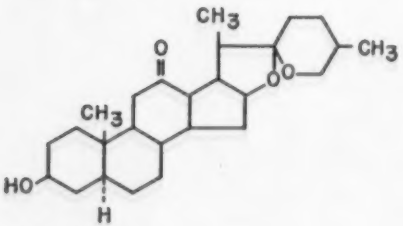
2. Alkaloids. The mescaline alkaloids, based on the structure of mescaline itself (3,4,5-trimethoxy-β-phenylethylamine) have achieved substantial recognition in the United States since their characterization by Spaeth and associates over the period 1919 to 1939 and their utilization



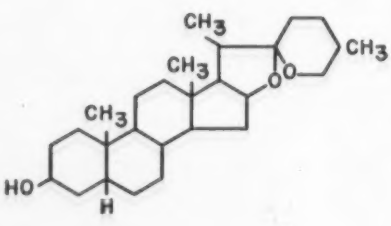
DIOSGENIN



SARSASAPOGENIN



HECOGENIN



TIGOGENIN

Fig. 1. Structures of sapogenin cortisone precursors.

in Europe for treatment of mental disorders. Synthesis of many of the alkaloids has already been achieved; however, the use of the natural sources of the materials still offers promise in many areas. The alkaloids are generally found in the true cacti, notably the Cereus species. *Opuntia vulgaris* (Miller), a jointed cactus of the type of prickly pear or cholla, is reported to contain alkaloids also (118). Reti (118, 120) has reviewed the subject of the cactus alkaloids at great length.

These alkaloids all contain the β-phenylethylamine skeleton. The primary amine group may be alkylated and the resulting secondary amine quaternized, to yield the quaternary alkaloids, or cyclicized. Cyclization on the nitrogen yields indole derivatives; cyclization on the carbon of the alkyl substituent adjacent to the nitrogen yields tetrahydroisoquinoline derivatives. Leach (97), in studies at Tulane of mental therapy using these alkaloids, has reported that the indole derivatives are most effective. The relationship of the various anhalonium alkaloids is illustrated in Fig. 2.

It is of interest to note the preliminary correlation among the various anhalonium alkaloids and reserpine. Woodward and associates (166) recently reported the total synthesis of reserpine and proposed the structure presented in Fig. 3. If this formula is divided across plane AB, the indole nucleus, described by Leach as being essential to the actual therapy of mental disorders, is revealed. If the same formula is divided across planes AC and DE, the tetrahydroisoquinoline nucleus is revealed, with ether linkage substitutions in the 6- and 7-positions (with respect to the nitrogenous nucleus only). The presence of the 3,4,5-trimethoxyphenyl radical is also of interest.

Synthetic condensation and cyclization of mescaline into 1-methyl-6, 7, 8-trimethoxy-1, 2, 3, 4-tetrahydroisoquinoline has been described by Castrillon (27).

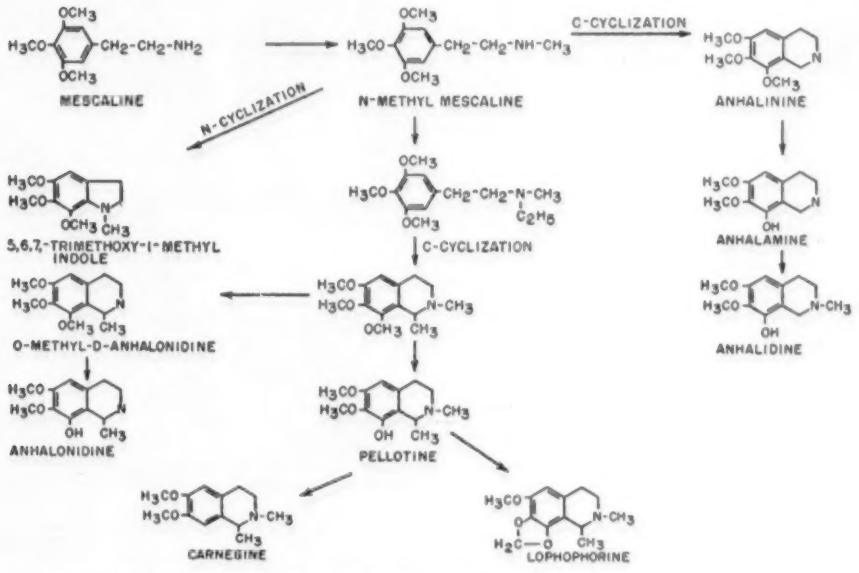


Fig. 2. Some structural relationships of mescaline alkaloids.

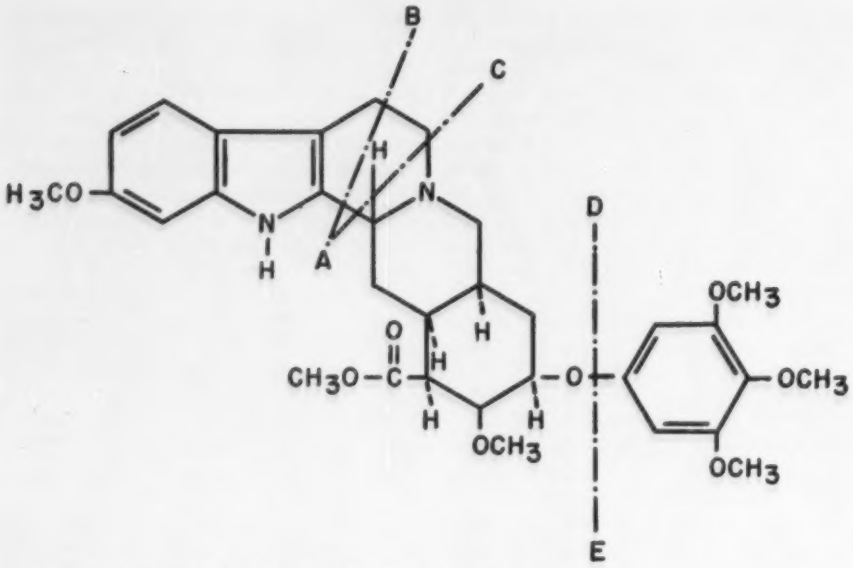
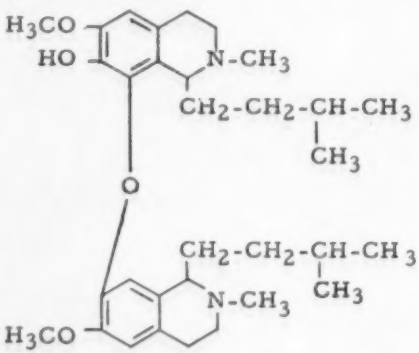


Fig. 3. Structure of reserpine (after Woodward).

Powell and Chen (116) report that pilocereine possesses anti-malarial activity equivalent to quinine in the treatment of canaries. The birds were given oral doses of 15 mg. of pilocereine per kg. of body weight. These results provoke some interesting reconsiderations of correlation of structure with antimalarial activity. Generally, laboratories participating in the OSRD antimalarial screening program from 1941 to 1945 reported that the isoquinoline nucleus, per se, was not promising as an antimalarial precursor. This work indicates that some antimalarial potential may still be present in the cactus alkaloids. Djerassi and associates have also studied the cactus alkaloids recently. The isolation, purification, and structure proof of pilocereine and piloceredine, the "dimers", were the work of Djerassi's group (46, 50, 57, 58). Of probable importance is the fact that pilocereine is essentially a "dimer" of the isoquinoline alkaloids, as shown by the following formula (57).



An interesting correlation appears to exist between anhalonine and lophophorine, and the popular insecticide synergists piperonyl butoxide, "Sulfoxide," and the newer "Sesoxane." All four materials

have the 3, 4-methylenedioxyphenyl fragment comprising part of their molecular structure (Fig. 4). This radical has been described by Beroza and Barthel (13) as being the essential portion of the more effective synergists for pyrethrines and similar insecticides.

Experimental psychiatry using mescaline, diethyl lysergic acid amide, and an uncharacterized alkaloid extracted from what was apparently an Italian species of *Opuntia,* is reported by Buscaino. Syndromes resembling schizophrenia were produced (24).

The effects of the mescaline alkaloids have been subjectively studied recently by Aldous Huxley (89). Huxley described his feelings during a period of mescaline intoxication. No "madness" or loss of control, so typical of marijuana and other alkaloids such as cocaine or morphine, was noted. The mescaline alkaloids are not considered to be habit-forming, as is the case with morphine and its derivatives.

3. Miscellaneous Drugs. It was reported earlier (35, 115) that prickly pear cactus possessed an antidiabetic factor. Several years later, a U. S. patent was granted covering the particular fraction of the cactus extracts known to contain this factor (83). Unofficial, but completely independent reports from the Mexican States of Coahuila and Jalisco indicate the use of cactus by the local natives to cure or prevent diabetes. This cactus extract has the advantage over insulin that it can be taken orally; it has the further advantage over "Orinase," the newly-developed United States oral anti-diabetic, that no untoward effects have yet been reported, as has been the case with the latter. Garcia, in the Philippines, reports

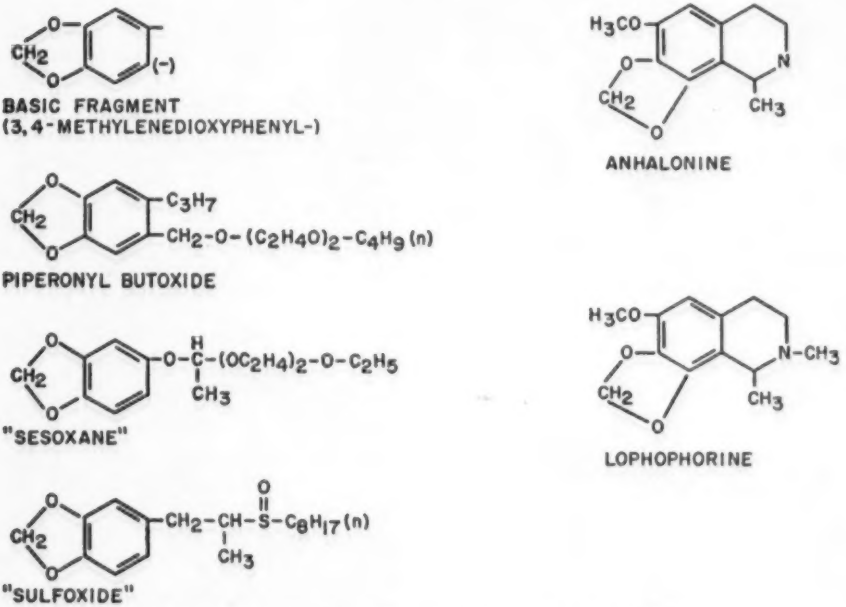


Fig. 4. The 3, 4-methylenedioxyphenyl fragment in synergists and alkaloids.

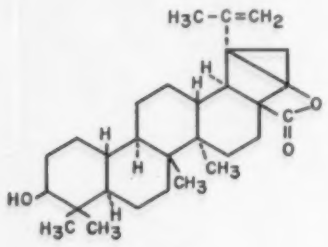
the results of clinical tests on plant extracts containing hypoglycemic (insulin-like) principles present in various plants indigenous to the area (73-77). Garcia designated the materials as "Plantisuls," or plant insulins, and concluded from his tests that these "Plantisuls" were as effective as insulin (from pancreas) in total dosage requirements of under 200 units. A tablet form of the material is preferred; the active extract is apparently reasonably stable in this form (77).

One major disadvantage inherent in antidiabetic cactus extracts as such is that they are not stable in the liquid form as extracted and that they ferment, hydrolyze, or otherwise decompose upon standing. Little, if any, development work has been done on this problem.

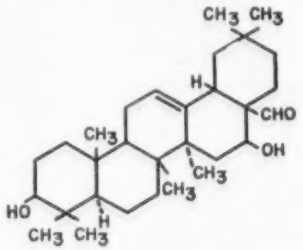
Much medical research is directed toward a drug, or drugs, active against tuberculosis. In this connection, Fitzpatrick (69) reports that extracts of St. John's Wort (*Hypericum perforatum*) are effective against *Mycobacterium tuberculosis* at 1:80 dilution, or higher.

The active pigment of St. John's Wort, hypericin, has long been a nuisance to many sheep and cattle ranchers. This, or a similar pigment, is also found in the *Agave lecheguilla* (37) and is photodynamic. This property may limit the usefulness of hypericin and related compounds until it can be clinically proved that the photosensitizing properties are not dangerous to man. The sand burr, or goat head (*Tribulus terrestrius*), also contains some similar pigments. A review of these pigments has appeared recently (21). An Austrian patent (103) claims the use of St. John's Wort, along with other ingredients, as a hair restorer!!

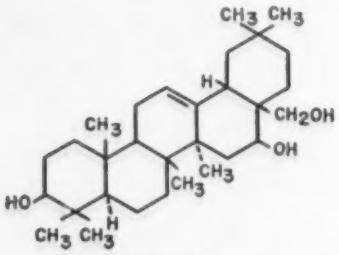
The triterpenoids, compounds similar to the steroids but based on a saturated cyclopentanochrysene nucleus, have been investigated by Djerassi and associates (51-56, 59, 60). The formulas of several of these materials are presented in Fig. 5,



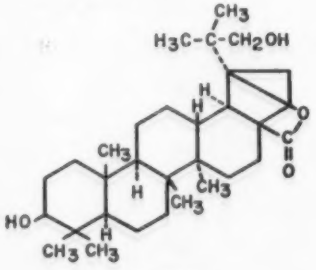
THURBEROGENIN



GUMMOSOGENIN



LONGISPINOGENIN



STELLATOGENIN

Fig. 5. Triterpenoids (after Djerassi, et al).

the structure would indicate potential pharmaceutical activity, perhaps paralleling the steroids. Some cardiac therapeutics are possible.

An alkaloid extracted from Argentine mesquite *(Prosopis ruscifolia)* has been shown by Cercos to be effective against Staphylococcus aureus (28).

Extracts of the night-blooming cereus *(Cereus grandiflora)* were utilized in a pharmacological study by Hepburn and associates (87). Electrocardiograms revealed that abnormalities were produced but in no specific pattern. Blood sugar varied within normal limits.

B. Sugar and Starches

Even with all the earlier work of Anderson, Sands, and associates on mesquite gum and other plant gums, some research continues to be reported on means of improving the yields of l-arabinose, the major sugar of mesquite gum. Cramer (33) utilized ion-exchange resins to remove the impurities from mesquite gum hydrolysed with aqueous sulfuric acid. The purified solution was concentrated in vacuo. Hudson (88) utilized $Ba(OH)_2$ to reduce foaming in another improved process of obtaining l-arabinose from mesquite gum.

Zaragoza (168) utilized honey mesquite as a source of invert sugar. The stalks were crushed in an inert atmosphere, and the tannins present were precipitated with lime.

An East Indian Agave *(Agave vera-cruz-A. lurida)* has been intensively investigated by the Council of Scientific and Industrial Research of the Republic of India (8, 14-16, 95, 128, 133-5, 169). The main edible portion consists of polyfructosans. The dried plant, extracted with methyl alcohol, yielded 68% solubles and 32% insolubles. Both fractions yielded fructose on hydrolysis. Only fructose was obtained from the press juice; no glucose was found.

Yucca starch is utilized in a patented reaction with substituted ammonium hydroxides (79).

Of side interest is the report that a stevioside containing three glucose units has been isolated from a wild shrub (*Stevia ribaudiana* Bertoni) indigenous to Paraguay (70). The extractive is 300 times as sweet as sucrose and does not have the bitter after-taste caused by saccharin.

C. Foods and Food Products

Investigation of *Agave vera-cruz*, mentioned above, was primarily undertaken by the East Indian research group for its potential food value. Extraction of 56 lbs. of woody stem fiber with water and concentration of the extract yielded 1.2 gallons of syrup containing 7.6 lbs of fructose (8). A pilot plant has been set up to isolate the fructose (95). The plant material is extracted with hot water, filtered, and hydrolyzed with H_2SO_4. After hydrolysis, the acid is neutralized with lime, the slurry filtered, and the filtrate evaporated to 80% solids. The fructose content of this syrup indicates a similarity to honey. A pectin-like substance was found in the stem residue but proved to be a poor jelly intermediate (128). An enzyme, transfructosidase, which builds up glucofructans from sucrose with the subsequent release of glucose was isolated. Optimum enzyme activity was obtained at 37° C.; the enzyme is inactive at 55° C. (15).

It is of interest to note that cacti, mesquite, yucca, and practically every other species of xerophytic vegetation furnishes, or can furnish, raw material for honey bees. Much advertising value is made of the various honey sources, e.g., mesquite honey, etc. The fruit of the sahuaro cactus of Arizona (*Carnegia gigantia*), after ripening and splitting open, furnishes a most unusual source of honey (36). This honey is wine-red in color and has a tang, rather than the excessive sweetness of ordinary honey. Sources of and seasons for such honey are obviously limited.

Cactus candy is an old favorite. One type is made from the pulp of the "barrel"

cactus (*Echinocactus Wislizenii*) by cooking cubes of the pulp in sugar syrups until the pulp is tender. More recently, prickly pear fruit has been utilized to make candy. Other cactus fruit could be similarly utilized. Red prickly pear fruit has been utilized to prepare jelly. Artificial color and flavor are added, however.

Prickly pear cactus leaves for food purposes are currently on the market in Mexico and in delicatessens in the United States. The canned, diced cactus leaves, tasting similar to a combination of string beans and okra, are called "Nopalitos." The fresh leaf, with the spines removed, is occasionally offered in the Farmer's Market of San Antonio, Texas. In preparing the fresh cactus leaves, care should be taken to boil the vegetable in several changes of water, as the mucilaginous fraction is reported (11) to be a strong laxative. Perhaps, however, this fraction could be marketed as a medicinal (similar to Serutan) with proper formulation.

Of less commercial value, but of interest to the gourmet nonetheless, is the knowledge that yucca blossoms, dipped in beaten egg and sugar and French-fried, furnish a delectable appetizer. The delicate nature of the finished product would preclude wide marketing of these, however.

The Papago Indians used to ferment cactus fruit to produce a wine. Modern fermentation methods should make possible a delicious and novel beverage, with or without an alcoholic content. Carbonation of a water extract of the pulp of the cactus fruit, for example, might produce a soft drink of acceptable flavor and texture.

A study of aguamiel, pulque, and tequila was made by Sanchez-Marroquin (125-6). Very small amounts of readily fermentable sugars were found in eight species of *Agaves;* starch was not proved. Inulin was the predominant polysaccharide and fructose the predominant fermentable monosaccharide. The yeast was a big factor in determining the quality of the tequila obtained.

D. Resins and Gums

A study of anticoagulants and antilipemics by Constantinides, Cairns, and Werner (31) utilizing sulfated polysaccharides indicated that mesquite gum was inadequate for the purpose.

Gum acids are prepared from naturally-occurring exudate plant gums by action of a cation exchange agent in aqueous medium. The gum cation is replaced by H^+. This method removes impurities which support mold and bacteria (9).

Mucilaginous extracts of cacti can be used in water treatment. The polysaccharide gum fraction (extractible by cold water) will remove acetic acid, glucose, methylene blue, and eosin (2) and is also effective as a flocculating agent in the mineral dressing industry (36). The Silverbell Unit of American Smelting and Refining Co. has been reported to be using cactus extracts in their copper beneficiation procedures at Silverbell, Arizona, 54 miles N. W. of Tucson. A water conditioner called "Agava" is marketed in Mexico. This material contains extractives from Agaves similar to those from the prickly pear. The material is utilized as a cleanser, rust inhibitor, boiler water conditioner, detergent, and protective coating.

On a more fundamental level, Bonner and associates (20) report that the isoprene monomer is formed in vivo from acetic acid, or acetate salts. Most of the work was done on the Hevea rubber tree; however, guayule was mentioned. Carbon-14 was used as a tracer to elicit the biosynthetic mechanism.

A recent study of the constitution of mesquite gum has been undertaken by Smith and associates (1, 130).

E. Fibers

Utilization of yuccas and agaves for fiber purposes continues. Fortmann (72)

used a series of rolls to decorticate the fibers, followed by brushing. The fibers were then immersed in water, drained, bleached four hours in a sodium hypochlorite - sodium carbonate solution, washed with water containing a textile-softening soap, and dried.

A process and machinery for separating fibers and pulp of sisal and other fiber plants is claimed in a German patent (4). No details are available at the present time.

The treatment of agave and hemp fibers with $Al.^{+++}$ or Zn^{++} ions in sodium hydroxide, followed by treatment with rapeseed oil, was claimed to produce flexible fibers (136).

Nine strains of Agaves were tested by Lohani, Biswas, and Dhingra, using each of three different methods to decorticate the fibers (machine decortication, controlled water retting, or full-retting). Machine decortication was found to yield the strongest fiber (100).

Gautier and Bui (78) crushed the agave leaves between fluted rolls and removed the pulp and cuticle. Solvent extraction of the latter yielded a wax. Bruins (23) extracted the leaves first with trichloroethylene to obtain waxes and then treated the extracted leaves to obtain the fiber.

Ramie fibers were separated by digestion at pH 12.4-13.0, in a buffered solution. The alkalinity was obtained with ethylethanolamine (144).

Fine asbestos fibers dispersed in coarser uniform fibers obtained from yucca yield an excellent filter medium for gases (102). Liquid or solid particles 0.2-0.3μ cross-section can be 99.75% removed with pressure drops as low as 8mm. of mercury.

The subject of fibers has been reviewed by Thieme in Europe (142) and by Lathrop and Nelson in the United States (96).

F. Miscellaneous Extractives

Plant growth inhibitors were isolated from several plants, the mesquite *(Prosopis juliflora)* and the creosote bush *(Sarcobatus vermiculatus)* among them, by Bennett and Bonner (12). Isolated were: byakangelicin [$C_{16}H_{15}O_6(OCH_3)$]; isopimpinellin [$C_{11}H_4O_5(OCH_3)$]; and a derivative, [$C_{16}H_{15}O_5(OCH_3)$], of isobergaptein. All three extracts were toxic to tomato plants, the latter being the most toxic.

The use of various xerophytic plants as stock feed continues. Prickly pear cactus was heavily utilized in South Texas during the drought period of 1949-1956. By burning off the spines with burners designed especially for the purpose, many ranchers managed to tide their cattle herds through the dry spell. Fernandez (67) has analyzed the *Opuntia ficus-indica*, presumably a southern European cactus. Fresh yucca leaves are unsuitable as fodder because of the presence of HCN (probably as a cyanogenetic glycoside). The cyanide disappears upon drying for two to three weeks. Hay from yucca leaves analyzes 15-20% protein, 10-12% ash, 13-23% fiber, 45-60% carbohydrates, and fat in traces only (90). The nutritive value of the creosote bush has been examined by Duisberg (61). The phenolic content of the unextracted plant makes it undesirable for this purpose, but extraction of the stalks and leaves with alcohol renders them adequate as stock feed.

Walters (160) has studied the effect of seasons and years on the nutrient content of spineless cactus leaves picked for feeding purposes. The data, from South Africa, cover two feeding seasons.

Leonti (98) has studied the composition and nutritive value of Italian prickly pear cacti. On a dry basis, the plants contain 3.51% protein, 2.57% fat, 5.31% fiber, 17.60% ash, and 70.99% carbohydrates. Nutritive value is rated at 72.09% starch units.

Milicic (107) reports the presence of protein crystalloids in the epidermal cells of the cactus *Opuntia inermis*. The protein crystals are in the form of rhombic

platelets and are probably localized in the cell sap.

Ascorbic and dehydroascorbic acids were obtained by Giral and Medrano (81) from the *Agave lecheguilla*. Citric acid was obtained by fermentation of fructose from the *Agave vera cruz* with *Aspergillus niger* (99). Munsell and associates (109, 110) have extensively studied the composition of food plants in Central America. Yucca blossoms were found to contain 343-398 mg. of ascorbic acid per 100 grams of flowers.

Mesquite gum (106), yuccas, and prickly pear, or greasewood (170) have been utilized as soil conditioners. The latter materials are disintegrated and allowed to ferment under atmospheric conditions for five days or more. The fermenting, but non-putrifying extract, is applied to the soil directly, or in water. Mesquite gum is most effective in normal soils.

Walsh, Hawes, and Foulger (159) have utilized nonstarchy dried vegetable husks (sisal, peanuts, etc.) in 3-5% concentration, plus 0.75% by weight of a trivalent metallic sulfate [$R_2(SO_4)_3$] in soil to produce building blocks.

As has been mentioned in the preceding section, waxes are obtainable from sisal and other Agaves. Samples of sisal wax from British East Africa were evaluated as substitutes for carnauba wax by Raymond, Thorpe, and Ward (117). The gloss and gel properties were satisfactory, but emulsification proved difficult. The chemistry of the liquid wax obtainable from jojoba *(Simmondsia chinensis)* has been reviewed by Knoepfler and Vix (91). The wax is similar to sperm oil (cetyl palmitate), and other long-chain esters are present, rather than glycerides. Daugherty, Sineath, and Wastler have made an exhaustive economic survey of the jojoba shrub (41). A similar study has been made on candelilla wax (42).

Geochemical prospecting for copper, utilizing mesquite and scrub oak leaves in the vicinity of Ray, Arizona, has been described by Clarke (29). In this connection, it is of interest to note that the outcrop of the San Manuel copper deposit in Arizona has been completely outlined by growths of California poppies (137). Uranium has also been reported to be detectible by mesquite. Care should be taken, however, not to confuse the radioactivity of uranium salts with the activity of radiopotassium, which is also present in mesquite (66).

A flavonoside from the flower of *Opuntia vulgaris* has been extracted by Paris (114). The dried flowers were extracted with various solvents, including ethyl acetate. After concentration of the latter extract, yellow crystals of the flavonoside deposited out.

An insecticidal amide, Affinin, has been isolated from the roots of the Mexican plant *Erigon affinis* D.C. (171). It has been identified as deca-2,6,8-trien-N-isobutyl amide. The formula:

$$CH_3CH = CHCH = CH(CH_2)_2-$$
$$\begin{matrix} & & & & O & & & & CH_3 \\ & & & & \| & & & & | \end{matrix}$$
$$-CH = CH-C-N-CH_2-CH-CH_3$$

Duisberg (62, 64) has presented interim reviews of the subject of xerophytic plant utilization.

III. ECONOMIC DISCUSSION

Basically, the practical economy of the utilization of the xerophytic plants is dependent upon a fairly complete utilization of the extractives of the particular species involved. Agaves (century plants) yield fiber, sapogenins, and some miscellaneous extractives, which vary with the species. The best set-up, from an economic standpoint, is a processing plant which will recover all the extractives of value, and utilize any by-products as completely as possible, in combination with an adjacent or nearby plantation on which the plants are systematically cultivated. In Mexico, the use of hand labor is still probably feasible in many areas; in the United States, labor costs

will undoubtedly dictate a maximum of mechanization in all phases of cultivation and harvesting.

Machinery for recovering fiber still appears to be one of the biggest problems in this latter respect. Work has been done on various types of decortication machines since the turn of the century; yet work on an improved fiber-recovery machine continues at the U. S. Department of Agriculture's Belle Glade, Florida, research station. A harvester which will both collect and decorticate the leaves would be, of course, the ideal machine; however, the size differential existing among the various species of Agaves poses yet another problem in the design of such a harvester. A machine suitable for the giant *Agave sisalana*, for example, might well be completely unsatisfactory for the elfin *Agave toumeyana*, or the somewhat larger, but still small *Agave lecheguilla*. The reverse consideration also applies.

Some of the extractives, particularly the sapogenins, appear to be formed as a result of a drought-resisting mechanism. Therefore, if attempts to hasten growth by heavy irrigation are made, the yield of desired extractives *may* decrease. One answer to this problem is the use of cross-breeding. Guayule, for example, has been the subject of cross-breeding studies; these have resulted in an improvement in the yield of rubber (more favorably formed under adverse growing conditions), and a decrease in the time required for the plant to mature, from five years to three years. Trace element studies and the use of gibberellins and plant-growth hormones may also be beneficial.

Careful correlation between demand for and sources of the various extractives must be made. Cellulose, for example, is generally obtainable more readily and in greater yield from pine wood sources or cotton than from cacti or mesquite. Generally, most pharmaceuticals are also manufactured synthetically, once the molecular structure is determined. The anhalonium alkaloids are rapidly becoming the subject of synthetic studies. On the other hand, the steroids always have been obtained from natural sources, since the cyclopentanoperhydrophenanthrene steroid nucleus, together with the attendant angular methyl groups· has not been successfully or economically synthesized.

The foregoing remarks have generally been concerned with plants whose utilization requires that they be cut down or uprooted. In some cases, such as the prickly pear, uprooting is unnecessary, and generally, the plant will grow back fairly rapidly. Yuccas and Agaves generally require replanting, however, as do most of the cereus cactus species. Some species of Agaves, however, will spread from roots. These considerations, in conjunction with the growth rates of the plants in question, all tie in together to determine the size of an optimum plantation and processing operation. Obviously, it might be necessary to allow some of the plants to go to seed for replanting.

It has been assumed that the cultivation-processing operation described above will have utilities of some sort available. The plants themselves may not require much water for growth purposes; however, process and some domestic water in the general area would almost surely be mandatory. Some heat, for power if nothing else, would also be prerequisite. In case the operation is far removed from a power line or power distribution system or a source of fuel, consideration could be given to atomic energy or solar energy. Some radioactive ore deposits have been reported in Mexico, primarily in the vicinity of Hermosillo, Sonora. These are, however, very closely controlled by the Mexican Government. Solar energy offers a very real possibility, inasmuch as the area in which the vegetation under discussion grows is also blessed with an abundance (if not, indeed, a surplus) of sunshine. Over a dec-

ade ago, the Russians were reported using a helioboiler to produce steam and power at a fruit cannery in southern Siberia near the Indian border (172). Recent conferences on solar energy in Phoenix and Tucson, Arizona, indicate the immediate practical potential of solar energy.

Legal aspects of these plants as a source of industrial raw materials would loom large only if the wild plants were chosen. In some cases, such as the *Agave lechegüilla*, ranch owners would be glad to see them removed. Prickly pear and other Opuntia cacti are somewhat anomalous. In some areas, notably Australia, South Africa, Kansas, and the Texas panhandle, the prickly pear is regarded as a nuisance, and eradication methods including biological control have been adopted. In south Texas, on the other hand, ranch owners realized the feeding value of prickly pear during the 1949-1956 drought and consequently are loath to allow collection or removal of the cacti from their property. Federal subsidies to clear off the prickly pear have been spurned in the latter area. As an extreme case, Arizona has some rather severe laws protecting cacti, most especially the Sahuaro (*Carnegia gigantia* Br. and Rose), which bears the state's flower. One stand of these cacti, east of Tucson, is a National Monument under U. S. Government supervision and protection.

The conclusion is simple—the potential is here; we need but to study it and develop it further.

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Cassava Leaf Protein

Crude protein content of the leaf of cultivars of* Manihot esculenta *is very high. There are no analyses of nutritionally essential amino acids, but certain evidence indicates that cassava leaf may be of value in protein-rich diets.

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Introduction

One of the more outstanding nutritional needs of people in the tropics is for higher protein levels in the diet. It is interesting to note that in certain areas of tropical Africa, where cassava *(Manihot esculenta)* is one of the most abundant crops, the young foliage of cassava plants is commonly used as a vegetable in the native diets.

If the cultivars used in Africa contain approximately the same quantities of crude leaf protein as those of the Jamaican cultivars, there may be major significance to correlate the distribution of the habit of eating the foliage of *M. esculenta* among the natives in Africa with the occurrence and absensce of the protein deficiency disease "kwashiorkor" (Trowell, 2). I have been unable to obtain information on the distribution of the areas in Africa where the foliage is used as a vegetable or of the presence or absence of "kwashiorkor" in such areas. In a feeding experiment with milk cattle in Costa Rica, Echandi (1) demonstrated that a mixture of dried yuca (cassava) leaves with wheat bran, rice, and cotton seed cake provided a diet nearly comparable with a similar mixture in which dehydrated alfalfa replaced yuca. On a cost basis, the pulverized cassava leaf meal was superior to the alfalfa in Costa Rica, where alfalfa leaf meal is an expensive import.

Methods

In the course of my studies* of the variation within the species *M. esculenta*, a cooperative endeavor with the Agricultural Chemistry Section of the Jamaican Department of Agriculture was established to analyze several constituents of the cultivars growing in Jamaica. Cuttings of plants from many areas of Jamaica (see tables below) were grown in two experiment stations, one the Bodles Experiment Station near Old Harbor, Jamaica, and the other the Grove Place Experiment Station, Mile Gully, Jamaica. At Bodles the cultivars were grown under irrigation in a plastic marine clay. At Grove Place no irrigation was employed, and the soil is a friable "red earth." Samples were taken from mature or nearly mature plants (11 to 12 months). Leaves of varying size, from just mature to small and under-developed at the stem apex, were included in the sample for each plant. Petioles are not included. The protein analyses given in the following table are the results of this study.

* Supported in part by National Science Foundation Grant #G-1309.

Discussion

No knowledge is yet available as to whether cassava protein is "nutritionally complete," but the fact that the percentages of crude protein are very high (comparing favorably with alfalfa) indicates that there is some chance that the leaf protein of cassava will be of significance for protein-rich diets. Quantitative and qualitative studies of amino acid composition of the leaf protein are needed

Another matter of importance for further investigation is the age of the plants when samples are taken. The foliage of the mature cassava plant is usually a

ANALYSIS[1] OF CRUDE PROTEIN[2] IN LEAF OF CASSAVA
Samples from Bodles Experimental Station, Old Harbor, Jamaica

% Crude Protein (Dry Weight)	Cultivar	Origin of Cultivar in Jamaica
20.6	New Green, Bitter	Ellen Street, Manchester
21.1	Bygrave, Sweet	Alva, St. Ann
22.1	Blue Bud Bitter	Mt. Olivet, St. Ann
22.8	Hafoo Sweet	Bodles, St. Catherine
25.3	Catch Thief	St. Thomas
25.7	Government	Restoria, Manchester
25.9	Bobby Hanson	St. Thomas
25.9	Sour Bammy	St. Thomas
26.1	Portland #1 White Stick	Nonsuch, Portland
26.5	Cashew Long Leaf	Bogue, St. Elizabeth
26.7	New Stick	St. Thomas
27.4	Who-fe-Patrick	Ellen Street, Manchester
27.5	Duff House Long Leaf	Ellen Street, Manchester
27.7	Black Stick Buck-Buck	Black River, St. Elizabeth
27.7	White Cuban	St. Thomas
27.8	New Jacket, Bitter	Queenbury, St. Elizabeth
27.8	Portland #5 Blue Bud	Caenwood, Portland
28.2	White Root, Brown Stick	Rocky Hill, St. Elizabeth
28.2	Portland #3 Agricultural	Hope Bay, Portland
28.6	Portland #2 Sugar Loaf	Nonsuch, Portland
28.8	Yellow Saunders	St. Thomas
29.0	Smalling Sweet	Red Bank, St. Elizabeth
29.1	Damsel Sweet	Bogue, St. Elizabeth
29.2	Catch Thief, Bitter	Pratville, Manchester
29.5	Long Leaf, Black Stem	Black River, St. Elizabeth
29.5	Portland #6 White Stick Sweet	Windsor Castle, Portland
29.5	Ulcer Sweet	Middlesex Dist., St. Ann
29.7	Gordon Bitter	Santa Cruz, St. Elizabeth
29.9	Long Leaf, White Tuber	St. Elizabeth
29.9	Bullet Tree	St. Thomas
30.0	Blue Chambers, Sweet	Bodles, St. Catherine
30.3	Portland #4 Cotton Tree	Hope Bay, Portland
30.4	Bobby Hanson	St. Thomas
30.4	Esther Bitter	Bogue, St. Elizabeth
30.7	Blue Top, Bitter	Santa Cruz, St. Elizabeth
31.1	Yellow Stick	Ardock Dist., St. Ann
31.1	New Green Bitter	Ellen Street, Manchester
31.1	Brown Stick, Bitter	Pepper, St. Elizabeth
31.5	Richmond Stick	St. Thomas
31.5	Yellow Belly Sweet	Port Maloney, Manchester
31.6	Elmo Stick	St. Thomas
31.7	Fowl Fat, Sweet	Bodles, St. Catherine
31.8	Westmoreland Bitter	Bogue, St. Elizabeth
32.1	John Henry Bitter	Ellen Etreet, Manchester
32.3	Mulling, Bitter	Cleveland Canny, Manchester
32.4	Eye Water, Bitter	Red Bank, St. Elizabeth
32.6	Bunch of Keys, Bitter	Pepper, St. Elizabeth
32.7	Marlie Hill	Big Yard, St. Elizabeth
32.8	Agric. White Stick Sweet	Pusey Hill, Manchester
33.0	White House Bitter	Mt. Olivet, St. Ann
33.1	A.G.R. Sweet	Hope Bay, Portland
33.1	White Heart Sweet	Lititz, St. Elizabeth
33.1	White Brown Stick Bitter	Santa Cruz, St. Elizabeth
33.2	Laura Bitter	Lititz, St. Elizabeth
33.4	New Green	St. Marys, St. Elizabeth
33.6	Yellow Heart Sweet	Lititz, St. Elizabeth
34.4	White Margaret Bitter	Pepper, St. Elizabeth
34.5	Smalling Bitter	Santa Cruz, St. Elizabeth
34.7	Sweet Cassava	Dumbarton Dist., St. Ann
34.8	Walters Bitter	New Forest, Manchester
36.1	Rodney Bitter	Pratville, Manchester

Samples from Grove Place Experiment Station, Mile Gully, Jamaica

22.1	Bitter Sweet #101	Middlesex, St. Ann
22.5	Agric. White Stick #76	Pusey Hill, Manchester
24.5	Bull Tiger	———
25.3	Smalling	Red Bank, St. Elizabeth
25.5	Red Stick Sweet	Iron Mt., St. Ann
25.7	Esther #54	Bogue, St. Elizabeth
25.8	Mullings	Spring Garden, Trelawny
25.8	Blue Bud #104	Ardock, St. Ann
25.9	White Margaret #51	Pepper, St. Elizabeth
25.9	Damsel #80	Bogue, St. Elizabeth
26.1	Blue Bud Sweet #90	Middlesex, St. Ann
26.3	Egg Yolk #88	Spring Garden, Trelawny
26.4	Rodney	Pratville, Manchester
26.7	Sweet Westmoreland	———
26.7	Westmoreland #46	Bogue, St. Elizabeth
26.7	White Stick #34	Norsuck, Portland
27.0	Yellow Stick	———
27.6	Yellow Belly Sweet	———
27.6	White Cuban	———
27.9	Ingram No. 77	Alva, St. Ann
28.2	Sweet Cassava #97	Dumbarton Dist. St. Ann
28.3	Blue Bud #105	Middelsex, St. Ann
28.6	Cashew Long Leaf #48	Bogue, St. Elizabeth
28.7	Red Stick #41	———
28.8	Bunch of Keys #73	Trelawny
28.9	Eye Water #43	Red Bank, St. Elizabeth
28.9	Long Leaf White Tuber #55	St. Elizabeth
30.0	Marigold	———
30.3	Blue Bud Sweet #91	Rocky Hill, St. Elizabeth
30.5	Marlie Hill #56	Big Yard, St. Elizabeth
30.8	Brown Stick #1	———
30.8	Gordon #40	Rocky Hill, St. Elizabeth
31.0	Pusey Sweet #75	Pusey Hill, Manchester
31.0	Cotton Tree #59	Hope Bay, Portland
31.4	Blue Stick #12	Albert Town, Trelawny
31.4	White Stick #7	Troy Land Settlement
31.8	Blue Top	———
32.0	White House #19	———
32.0	Short Leaf Cotton Tree #14	Middlesex, St. Ann
32.4	Blue Top #39	Rocky Hill, St. Elizabeth
32.5	Smalling #49	Pepper, St. Elizabeth
32.7	Mt. Pleasant #57	Pusey Hill, Manchester
32.8	Tall Leaf Cotton Tree #15	Middlesex, St. Ann
33.1	Walters #58	New Forest, Manchester
33.3	White Stick #52	Pepper, St. Elizabeth
36.4	Laura #53	Lititz, St. Elizabeth

1. Analysis made by the Agricultural Chemistry Section, Department of Agriculture, Hope Gardens, Jamaica.
2. Standard Kjeldahl methods were used in the analyses (Total N x 6.25)

sparce "top-knot" on the tall stems. No analyses were made on two- to four-month-old plants when the total amount of foliage is proportionately much greater. It would be valuable to make comparative analyses of crude protein content and amino acid assays on plants which are mature for root production and young plants which have the highest proportion of plant to leaf surface.

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also support an algal flora—the sloth and red-colored green algae of its hairs, the turtle and its characteristic filamentous *Basicladia*, the green chlorella-like examples known as "Zoochlorellae" which make green Hydras green. Within the alimentary canals of various animals, including man, evidence of surviving algae has been found. In some cases this appears to form a part of the normal intestinal flora.

Businessmen, engineers, and others who are turning algae to man's use will benefit from the chapter on "Algae and Human Welfare." Certain algae produce noxious effects in drinking water supplies; others are valuable in sewage disposal. Fish hatcheries may suffer from the effect of mats of algae which by utilizing the oxygen at night can so deplete it as to kill the fish. Methods of control in such problems, such as the use of copper sulfate, sodium arsenite, biological and mechnical means, are surveyed. In reference to food supply, direct use is made of kelps, Irish moss, dulse, and porphyra in some countries. In ours we may be surprised at the amount of seaweed extract we consume in the form of ice creams.

In terms of modern-day trends in research, culturing methods and the important potential use as oxygen producers for space and submarine survival are important current efforts. *Chlorella* is already a food supplement for rats and chickens. Nitrogen-fixing potentialities remain to be controlled and unexploited for agricultural purposes. The nerve toxin from *Gymnodinium brevis* abounds in the red tides off Florida and in the Gulf of Mexico. This creates a tremendous biological control problem in which the causative organism is already known. Yet, despite wide research efforts, no adequate technique has been developed. Even more difficult is the basic biological problem of what causes algae to be distributed in such a discontinuous manner. Within apparently identical habitats of a given lake, or in similar adjacent ponds, the same species does not prevail. On the other hand, the same form may turn up in widely separated regions such as India, the Philippines, and Massachusetts.

Methods of collecting, preserving, and studying the algae (which are usually topics for the introductory chapters in books) are strategically discussed at the end after the reader's interest merits this attention.

The text is well printed on pleasing paper. The diagrams are generally excellent, beautifully done, and apropos. The half-tones, although fine, vary in quality. Some have gained and others have suffered in this reprinting. In overall consideration, however, if one can ignore the hardly conservative price, this book provides delightful and instructive reading.

RICHARD D. WOOD

Edible Wild Plants of Eastern North America. M. L. Fernald and A. C. Kinsey. Revised by R. C. Rollins. i-xii + 452 pp. Harper and Brothers, N. Y. 1958. $6.00.

Very little alteration has gone into this revised edition of a pleasurable book. A few plates have been redone, and several plant names have been changed to bring them in accord with later knowledge.

The book is "useful" in the sense that one can take it to the country and with the help of it find edible plants; it cautions against those which are poisonous; it even challenges one to try some which might be considered "dangerous." Even more than this, there are homely bits of the real history of our country. People of an inquisitive, adventuresome nature have reported their finds, and many are quoted in this text. Indian usage is frequently reported. The authors themselves have sampled most of the plants mentioned. Before the advent of our present-day food distribution system, people frequently went to their surrounding natural habitats for either basic foodstuffs or for the extras which make foods more palatable or the diet more varied.

One may find substitutes for tea and coffee and also plants good for "nibbling." If one were forced to do so, it would be possible to exist for a while away from civilization without other foods. This is not the intent of the book, however, since it is not written as a "survival manual." It is, as stated, for "nearly everyone who has a certain amount of the pagan or gypsy in his nature . . . ."

DAVID J. ROGERS

Algae: The Grasses of Many Waters. Lewis Hanford Tiffany. 2nd. ed. xv, 199 pp., 41 pls., 13 figs., Charles C. Thomas Publishes, Springfield, Illinois. 1958. $6.50.

In this twentieth anniversary year of the publication of Dr. Tiffany's little book on algae, the text and plates prove just as meaningful as ever. Remarkably little change has been required to bring the information up to date. The 28 page increase in size from that of the first edition is largely found in a timely new chapter on "Algae and Research" and to a lesser extent in occasional modifications. The original book remains remarkably intact. A few changes in plates will be found, such as a revision in that on "Fresh-water diatoms and desmids," "Glimpse through the microscope," and "Vaucheria." Naturally, the great advances in knowledge of plant pigment have demanded an entirely new table on their distribution among the algal groups. The list of references is likewise brought up to date.

In an era of ponderous reference texts on the one hand and summary type how-to-know books on the other, this volume is a refreshing departure from American conventions. It is enjoyable reading! With commingled wit, homely humor, and artistic use of simplicity, intricate and specialized topics are made clear and factual. Evolution, sexuality and life cycles, water relations and osmotic phenomena, food syntheses and the part played by raw materials, respiration, and growth create a background of fundamental biology. On this groundwork, the details of phycology are woven.

For the beginner, the book is a stimulating entree to an intriguing field. The college student will find questions and answers on many topics he should have considered all along but somehow has managed to elude in his course of study. The sanitary engineer, biological technician, or conservationist, whose work touches on algae, will find just exactly the type of discussion and illustrations needed to orient him in his work. The professional phycologist will enjoy reminiscing with this excellent review.

The chapters lead naturally from what algae are, how they make their food, how they grow and reproduce and survive. The discussion flows smoothly to ecological aspects in the algae of standing fresh water of lakes and ponds, running fresh water of rivers and streams, and finally the sea. Here, again, the plates are of special value, for a separate page illustrating the more frequent forms in each of the habitats is provided.

Unique are the chapters on forms which thrive in unusual habitats Soil algae, for instance, are widespread and abundant and apparently constitute a definite flora. When excessively abundant some are deleterious to other vegetation such as the *Nostoc* which accumulates in a gelatinous mass in tropical soils; others are valuable, such as the nitrogen-fixing bluegreens of rice paddies. Snow supports certain species, and colors such as yellow, green, red, and even black occur in snowfields. They survive at −40° C., but most species are active primarily in the melting surface layer at a temperature close to that of winter sea water. The strange array of relationships between algae and other living things is surprising. *Protococcus*, the green growth on trunks of trees, is an epiphyte; while the ubiquitious lichens represent a system of mutual benefit between the algae and fungal filaments comprising the symbiotic union. *Anabaena* filaments grow within the water fern *Azolla*, requiring apparently nothing but space, whereas, the tropical *Cephaleuros* is a true parasite. On tea, it produces symptoms known as "red rust." Some animals

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